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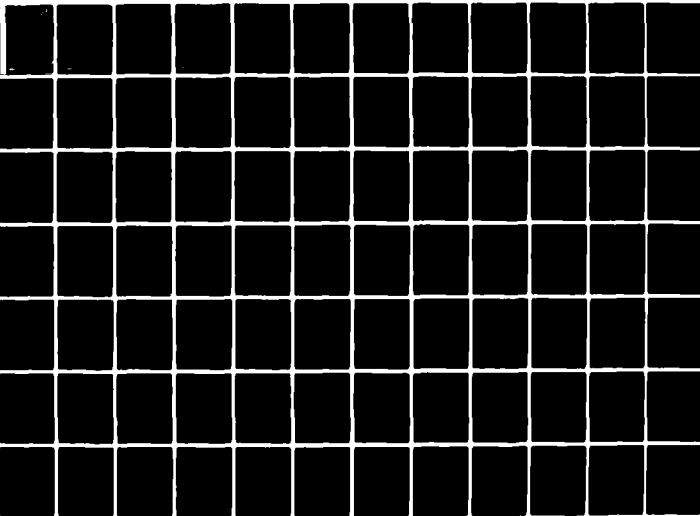
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Final Report

June 1981

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**AN EVALUATION MODEL CONCEPT
FOR RELATING TASK GROUP READINESS
TO LOGISTIC SUPPORT SYSTEM PERFORMANCE**

By: RICHARD H. MONAHAN

Prepared for:

DAVID W. TAYLOR NAVAL SHIP
RESEARCH AND DEVELOPMENT CENTER
BETHESDA, MARYLAND 20084

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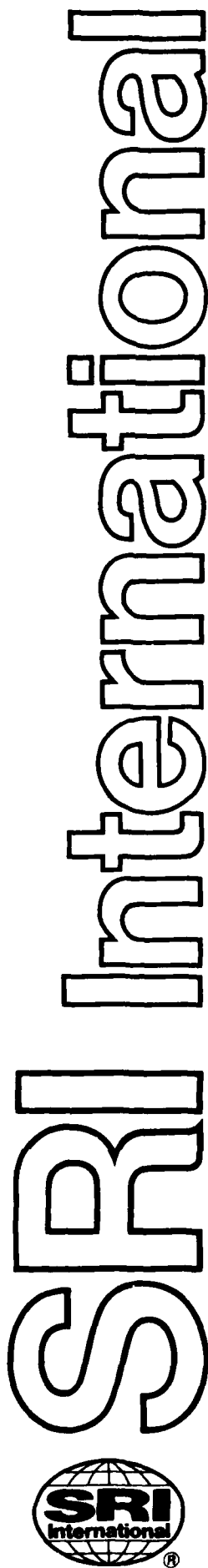
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SRI Project 8976

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chapter concludes with a brief overview of the application of the model concept to assisting a Navy planner in establishing an efficient allocation of limited resources to logistic-oriented programs that may enhance the readiness of Naval forces at the task group level of operations. Included in this chapter is a brief discussion of the manner by which the model concept should be implemented to establish a computerized readiness evaluation model.

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PREFACE

This report documents the analysis and findings of a research project conducted for the David W. Taylor Naval Ship Research and Development Center (DTNSRDC), Bethesda, Maryland. The sponsor and technical monitor was M.J. Zubkoff, Code 187, of DTNSRDC. The work was performed under Contract N00167-79-C-0197.

The research was performed in the Center for Defense Analysis (CDA) of the Research and Analysis Division (RAD) of SRI International. J. Naar is Director of CDA, and D.D. Elliott is executive Director of RAD.

R.H. Monahan was project leader and principal investigator. He was assisted by W. Schubert, who provided considerable insight for the formalization of readiness concepts.

I INTRODUCTION AND SUMMARY

A. Introduction

The objective of the research described in this report was to establish a method to relate logistic system performance to operational readiness at the task group level of the operational Navy. The concept of readiness has been drawing the increased attention of military planners and analysts in recent years. Merely defining readiness has been a difficult venture, and attempts to formalize a general definition have not received universal approval. Because of this, development of analytical tools to evaluate readiness has not kept pace with the multitude of efforts devoted to analysis of the effectiveness of military systems. The results of the research presented in this report hopefully provide a significant step forward in the readiness evaluation field. A summary description of these results is presented in the ensuing section of this chapter. The detailed results of the research are discussed in succeeding chapters. Chapter II presents a rather thorough analysis of the philosophy underlying readiness concepts. In Chapter III, a detailed description of a readiness evaluation model concept, linking the performance of logistic support systems to task group readiness, is presented. Chapter IV concludes with a brief overview of the application of the model concept to assisting a Navy planner in establishing an efficient allocation of limited resources to logistic-oriented programs that may enhance the readiness of Naval forces at the task group level of operations. Included in that chapter is a brief discussion of the manner by which the model concept should be implemented to establish a computerized readiness evaluation model.

B. Summary

1. Readiness Concepts

For the past two decades, numerous studies have been devoted to examining specific aspects associated with the concept of readiness.

For the most part these studies have concentrated on the specific problem on hand at the time, and little concerted effort was made to tie it all together to address the complete problem. One reason for this is the complexity of the problem itself, and another is the lack of a uniform interpretation of just what "readiness" means. A variety of definitions have been offered in the past. For the most part, the definitions include consideration of mission performance. In some cases, the reference is to missions assigned to the entity (unit, ship, weapon system, etc.), while in other cases the reference is to the missions for which the entity is organized or designed. This difference marks the principal factor of confusion that has probably been the nemesis in attempts to establish a coherent theory of readiness. The principal problem here is the need to consider "effectiveness" and "readiness" as two different, though closely related attributes. Readiness addresses the problem of an entity's living up to its potential, while effectiveness addresses the problem of how good this potential is, in consideration of opposing forces and variable environmental conditions. With this in mind, the definition of readiness should infer, in some way, a statement of the degree of fulfillment of an entity's maximum designed capability to perform its required missions or functions. Two other factors inherent in readiness considerations are echelon dependency and sustainability. Echelon dependency enters the problem through the specifications of mission requirements. At the very low echelon levels, mission requirements can generally be explicitly specified in narrow terms. At higher command levels, these requirements become more diversified, broader in scope, and less quantitatively definitive in nature. Thus the concept of readiness, being tied to mission requirements, will become more intangible in character as the level of organization moves up the command echelon hierarchy. Sustainability is another factor that is highly related to readiness through consideration of the time element. Most, if not all, missions have some time element implied, either explicitly or implicitly. Thus, the degree of fulfillment of an entity's potential to satisfy mission requirements--that is, its readiness--infers performance over some normal operating cycle. Sustainability, which would more usually address more extended time periods of time, refers more to ability of an entity

to maintain at least some threshold state of readiness over this longer time period.

Based on the above considerations, the following definition of readiness is proposed as a simple, usable definition of readiness and was adopted for use in this research:

Definition: Readiness is the degree to which an organizational entity is capable of performing, to its maximum potential, the missions for which it is organized during a normal operating cycle.

The selection of an adequate measure of readiness will depend on the requirements of the particular problem under investigation. The specific criteria for the selection of such a measure must consider such factors as the purposes for which the measure is to be used, the applicable echelons to be considered, and the availability of supporting data and evaluation tools. The types of measures fall generally within two different categories, depending on whether the underlying measurement system is ordinal-based or cardinal-based. An ordinal measurement system is one that assigns a rank ordering of value to a set of different system states, while a cardinal measurement system gives relative value information for different system states as well as rank ordering information. Cardinal-based measures, especially those using a continuous measurement scale, are much more useful than ordinal-based measures, but the feasibility of obtaining simple, meaningful cardinal-based measures decreases as the command echelon climbs higher up the ladder. At lower levels, simple measures can be defined that easily reflect the effects of small changes in parameters. However, at higher levels, such as those pertaining to task group performance, such simple measures do not pertain. There are so many parameters impacting on that performance that consideration of individual parameters will not generally exhibit any significant impact on resulting values of a simple measure. To alleviate this insensitivity the readiness measure must change with each echelon of command to reflect the global performance capability representative of that echelon. More often than not this change is also likely to result in a readiness measure that becomes more complex at the higher command echelons. This increase in complexity in turn requires more complex

evaluation tools, which themselves create an increased demand for supporting data. The choice of such a measure must weigh the advantages gained by using more complex measures against the added resources required to evaluate readiness in terms of these measures.

In the selection of an appropriate readiness measure, consideration must be given to the feasibility of using selected techniques as evaluation tools. Evaluation techniques can generally be classified under one of four classes: empirical, theoretical, subjective, and combinatorial. Empirical techniques are those that operate predominantly on observed or experimental data to establish functional relationships between selected resource factors and system performance parameters. These techniques provide for a high level of credibility, being based on hard data, but are not very useful in determining the causal effects of inputs on the output. In addition, extrapolation beyond the range of the test data can lead to erroneous and sometimes preposterous results. Theoretical evaluation techniques are those based on models of the causal relationships between input resources and output values of performance. Included in this category would be simple or complex analytical models and Monte Carlo simulation models. A major difficulty with these techniques lies in the justification of the numerous underlying assumptions made in the development of the associated model. In general, the larger the number of assumptions made, the less credible are the results. Reducing the number of underlying assumptions results in more complex models which require a larger expenditure of resources. Subjective evaluation techniques are those based on the judgements of one or more persons possessing expertise in the problem being investigated. These techniques can range from simple intuitional judgements, on up through subjective decisions based on certain quantitative or qualitative bases, to the use of the Delphi approach, where a group of experts collectively apply their subjective judgements in a systematic manner to establish logical relationships between resource inputs and performance outputs. Use of these techniques introduces biases based on different individual judgements. Combinatorial evaluation techniques simply refer to those techniques that possess a significant combination of the other three classes of techniques mentioned above. Although almost all evaluation techniques

have some semblance of being combinatorial, many fall predominantly under one of the other classes.

2. Task Group Readiness Evaluation Model Concept

The backbone of the task group readiness evaluation model concept is the readiness hierarchy structure that links logistic support factors to task group readiness. There are six levels in this hierarchy structure: Task Group, Task Group Operational Missions, Ship Missions, Ship Operational Capabilities, Unit Resource Areas, and Support Factors. The underlying concept of the model involves establishing readiness at each level of the structure in terms of readiness estimates established at the next lower level in the structure. For example, the readiness of the task group to perform its broad strategic mission can be derived from the task group's readiness in performing a set of operational missions required under the strategic mission definition. In turn, the readiness of the task group in performing a specific operational mission can be derived from the readiness of the individual ships of the task group to perform their required mission under that operational mission and so on down the readiness hierarchy structure. The possible task group operational missions defined in this study are: land strike, surface strike, subsurface strike, convoy defense, amphibious offense, amphibious defense, barrier, blockade, search/rescue, and area surveillance. An "idle mission" is also included as a catch-all for those time periods when the task group is not actively performing in one of the operational mission categories. The ship missions coincide in nomenclature with the task group operational missions, although the mission requirements imposed on each ship will, in general, differ in accordance with the individual ship's functions in support of the task group operational mission. The mission requirements for each ship will be delineated through the specification of the ship's required operational capabilities in support of that mission. These operational capabilities fall under six major group headings: target detection operations, radiation operations, mobility and support operations, enemy encounter operations, supply support operations, and command and control operations. The unit resource areas

fall under four headings: personnel, equipment, fuel, and mission expendables. For the model, each of these are further broken down into several resource subareas. The support factors, at the bottom level of hierarchy structure, represent the performance of the logistic support systems that provide support to the task group during both the initial outfitting stage and also while the task group is at sea. These support factors consider such items as initial availability of personnel, equipment, supplies and fuel; resupply factors; equipment reliability and maintainability; and so on.

The conceptual model formulated to address the problem of evaluating the effects of variations of the basic logistic support activities on the expected readiness of Navy task groups is depicted schematically in Figure 1. Down the center of the diagram, the various levels in the readiness hierarchy structure are indicated. The general flow of the model operations is depicted along the periphery. This begins with the specification of basic task group inputs that identify the overall task group mission requirements, task group configurations, and certain other selected performance requirements. A preestablished data base identifying the various intermediate requirements imposed on the individual ships of the task group, beginning with the ship missions and proceeding down to the unit resource areas, is then operated on to establish a basic set of requirements to be satisfied by the logistic support functions. A support factor model is then exercised to establish estimates of the expected readiness of each task group unit within the various unit resource areas. Although the computational procedures used for the different resource areas are varied, there is a general theme that is common to all of these. This general theme infers the establishment of a readiness function for the particular resource area (actually for each subarea and unit-type breakdown of a resource area). Three phases of computations are performed. The formation phase computations establish an initial embarkation value for this function. The physical deployment phase computations modify this value to account for changes that occurred while the task group was deploying to its intended at-sea deployment station. The on-station phase computations then establish the values of this

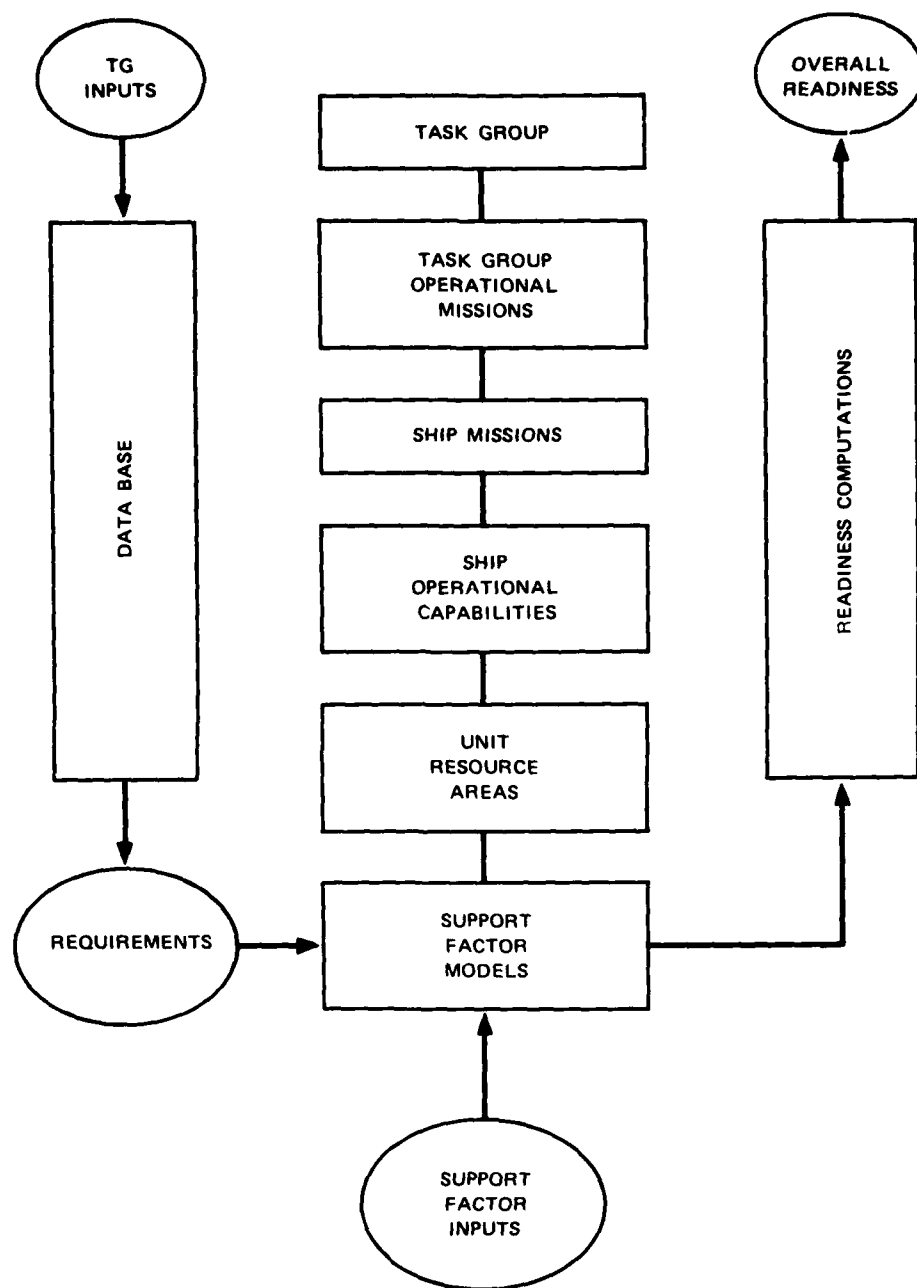
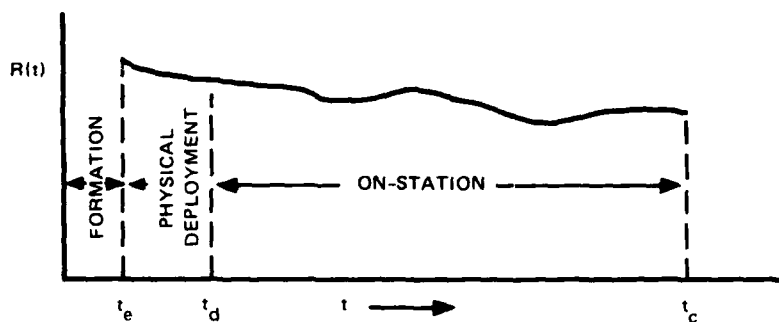


FIGURE 1 CONCEPTUAL MODEL STRUCTURE

readiness function during the duration of the task group's time on-station. The final output of the support factor model, for the particular subarea and unit-type breakdown of a major resource area, is the average value of this readiness function over the duration of the task group's time on-station. Schematically, this can be represented by the following diagram, where $R(t)$ denotes the readiness function, t_e the time of embarkation, t_d the time of arrival on-station, and t_c the time of completion of the task group's time on-station:



The average readiness, \bar{R} is then given by the integral of $R(t)$ from t_d to t_c . That is,

$$\bar{R} = \int_{t_d}^{t_c} R(t) dt$$

After completing the unit resource area readiness computations, the model then goes through a series of computations that generate an estimate of the overall task group readiness. These computations consider the interactive effects of the resource area readiness values on readiness at the various intermediate levels up through the readiness hierarchy.

3. Model Application and Implementation

The readiness evaluation model would, if implemented, serve as a convenient tool for evaluating readiness of postulated task group configurations under various assumptions relative to the performance of the logistic systems that provide support to the task group. These assumptions could represent the expected future payoffs of possible present funding of alternative exploratory development programs. Using changes in readiness as a decision criterion, the technical strategist, who establishes the allocation of exploratory development funds, could use results obtained from this model, coupled with a resource allocation method previously developed by SRI for DTNSRDC, to determine a preferred funding program from a set of possible alternatives.

The implementation of the evaluation model concept would require a significant effort, both in the actual programming of the model and in the data gathering activity, to establish the required model data base. However, once this implementation has been established, the benefits derived from the use of the model will far offset the cost of this initial investment.

PLATE

II READINESS CONCEPTS

A. General

Readiness, in one form or another, is an attribute that has been receiving increased attention by military planners and analysts over the past two decades. During this period, numerous studies have been devoted to examining specific aspects associated with the concept of readiness. However, for the most part, this research has concentrated on the specific problem on hand at the time, and little concerted effort was made to tie it all together to address the complete problem. One reason for this is the complexity of the problem itself, and another is the lack of a uniform interpretation of exactly what "readiness" means. This point was brought out quite clearly at the May 1974 Logistics Research Conference held at The George Washington University by the then Deputy Chief of Naval Operations (Logistics), Vice Admiral Walter D. Gaddis, USN, who, in addressing specific problems facing the the Navy in the logistics field, made the following statement:^{1*}

"An example is our need for a simple, usable definition of material readiness of Naval forces, a means of measuring it, and some perfectly definite input-output relationships. We need to be able to link resource inputs, and this means money, to any of the numerous potential outputs, and these mean military applications. We need to be able to predict not only how much the readiness measure will change, but also when it will change, as a result of changes in inputs. Finally, this readiness measure must be usable by horny-handed military managers."

Even today this need still exists. This is not to say that the problem has not been addressed in recent years, but merely implies the difficulty in finding workable solutions.

The remainder of this chapter presents a summary analysis of the readiness problem with regard to Naval forces. This entails the selection of a usable definition of readiness, followed by discussions of

*References are listed at the end of this report.

criteria for establishing suitable readiness measures and of the requirements for mathematical models to evaluate the input-output relationships that link resources to readiness.

B. Readiness Definition

The standard dictionary definition² of readiness, "the quality or state of being ready" is much too vague to be of use to planners and analysts in their attempts to measure, evaluate, or predict the state of readiness of various Naval units and organizations. From past studies addressing Naval readiness, a sample chronology of more specific definitions has been assembled and is presented in Table 1. As indicated by the modifying adjectives, many of these definitions refer to only certain aspects of readiness. Nevertheless, these definitions do have some common factors as well as distinct factors.

For the most part, the definitions include consideration of mission performance capability. In some cases, the reference is to missions assigned to the entity (unit, ship, weapon system, etc.), while in other cases the reference is to the missions for which the entity is organized or designed (compare Definitions 17 and 18 in Table 1). This difference marks the factor of confusion that has probably been the principal nemesis in attempts to establish a coherent theory of readiness--that is, a theory that would satisfy the needs of those measuring the present readiness of command units, of those attempting to evaluate the readiness of combined forces, and of those attempting to predict future readiness arising from, say, the introduction of revised SOP or improved weapon and support systems. The principal problem here is the need to consider "effectiveness" and "readiness" as two different, though closely related attributes. Readiness addresses the problem of an entity's living up to its potential, while effectiveness addresses the problem of how good is this potential in consideration of opposing forces and variable environmental conditions. In this sense, readiness is a controllable, and to a certain extent, absolute entity, whereas effectiveness is, to a large degree, uncontrollable and highly relative. With this in mind, then, the definition of readiness should infer, in some way, a statement of

Table 1

SAMPLE DEFINITIONS OF READINESS

Definition Number	Attribute	Definition *	Date	Agency or Author	Reference Number†
1	Logistic Readiness	"The ability to undertake, to build up and thereafter to sustain, combat operations at the full combat potential of the forces which are assigned to the combat commanders in those areas that are vital to the security of the nation."	May 59	H.E. Eccles	3
2	Naval Ship Readiness	"That quality or state of a naval ship whereby it is prepared for use or action of any kind which might develop in war, or preparatory to, or training for war."	Nov 62	J.E. Hamilton	4
3	Ship Material Readiness	"That quality or state of the non-human elements which compose a complete, fully found ship, whereby it is prepared for use or action of any kind for which its design is suitable, which might develop in war, or preparatory to, or training for war."	Nov 62	J.E. Hamilton	4
4	Personnel Readiness	"Relates to the capability of limited human resources at the disposal of the Navy to fulfill the above requirements within given monetary constraints." [Above requirements - the efficient operation of a ship requires that a certain number of people with a given variety of skills be present and that these skills be performed at a specified level of proficiency.]	Mar 65	Dunlap & Associates	5
5	Readiness	"The degree to which a complex system is capable of performing its assigned task."	May 66	J.A. White	6
6	Operational Readiness	"The condition or status of any military unit (or force) with regard to its capability or capacity to carry out the duly assigned operational mission (and/or objectives) and as such is broadly considered a function of that mission."	Jun 67	J.P. London	7

Table 1 (Continued)

Definition Number	Attribute	Definition*	Date	Agency or Author	Reference Number†
7	Overall Ship Readiness	"The capability of the ship to perform the mission or functions for which it is designed or organized."	Nov 68	S.A. Frank, W.B. Bruttke, W.H. Marlow, S.J. Mathis	8
8	Operational Readiness	"The probability that the system will be up when needed" [for a 2-state system].	Jun 69	M. Mazumdar	9
9	Complete Readiness	The availability of "resources" to meet requirements (implies quantitative statement of mission requirements--definition inferred).	Sep 72	I. Greenberg	10
10	Dynamic Readiness	"The ability of the unit under consideration to continue to perform in a satisfactory manner during the entire mission."	Sep 72	I. Greenberg	10
11	Overall Combat Readiness	The composite capability of an organization to perform its mission (definition inferred).	Jul 74	CNO	11
12	Mission Area Readiness	An organization's capability to perform in assigned primary mission areas (definition inferred).	Jul 74	CNO	11
13	Resource Readiness	A breakdown of readiness to the resource categories of personnel, equipment and supplies on hand, equipment readiness, and training.	Jul 74	CNO	11
14	Ship Readiness	"The capability of the ship to perform missions assigned to it."	Aug 74	S. Kaplan	12
15	Operational Readiness	"The capability of a unit, ship, weapon system, or equipment to perform the missions or functions for which it is organized or designed. May be used in a general sense or to express a level or degree of readiness."	Sep 74	JCS	13
16	Material Readiness	"The availability of material required by a military organization to support its wartime activities or contingencies, disaster relief (flood, earthquake, etc.) or other emergencies."	Sep 74	JCS	13

Table 1 (Continued)

Definition Number	Attribute	Definition*	Date	Agency or Author	Reference Number†
17	Combat Readiness	"Synonymous with operational readiness [Definition 15 above] with respect to missions or functions performed in combat."	Sep 74	JCS	13
18	Readiness	"The degree or extent to which a system or subsystem is prepared to immediately carry out any subset of an initially specified set of missions which may be assigned to it." [Note that readiness is a function of time.]	Jun 75	S. Kaplan	14
19	Readiness	"The degree to which the operating units in the force structure are capable of performing the tasks for which they were designed and organized."	May 78	CNO	15
20	Unit Readiness	"The capability of a unit or ship to perform the missions or functions for which it was organized or designed. The term may be used in a general sense or to express a level or degree of readiness."	May 78	CNO	15
21	Fleet Readiness	"The degree to which the force is ready to carry out its mission to wage prompt and sustained combat at sea." [Discusses further the inclusion of the deployment factor as well as personnel, training, equipment and support.]	May 78	CNO	15
22	Personnel Readiness	"Having the quantity of people to man the ships squadrons, and support activities to full allowance; the quality in terms of skills required to operate and maintain the ships, aircraft, facilities, and installed equipment, and the experience to provide organizational leadership and morale."	May 78	CNO	15

Table 1 (Concluded)

Definition Number	Attributes	Definition*	Date	Agency or Author	Reference Number †
23	Material Readiness	<p>"Refers to maintenance, both scheduled and unscheduled, and logistic support.</p> <ul style="list-style-type: none"> • Maintenance is accomplished at three levels; organizational, intermediate, and depot. [Further defines these levels of maintenance.] • <u>Logistic Support</u> - this part of material readiness refers to furnishing spare parts for ships and aircraft to be installed at any of the three maintenance levels. Also, logistic support in the context of material readiness includes the availability of combat consumables, fuel, and ammunition carried in the ship's hull." 	May 78	CNO	15
24	Training Readiness	"The combining of personnel and equipment in the operation of the ship and its embarked weapons system."	May 78	CNO	15

* Portions within brackets were added for clarity.

† Reference numbers refer to references listed at the end of this report.

the degree of fulfillment of an entity's maximum designed capability--that is, its maximum potential to perform its required missions or functions.

Reference to mission performance in such a definition also infers two other factors inherent in readiness consideration: echelon dependency, and sustainability. At the very bottom of the echelon hierarchy, mission or functional requirements can generally be explicitly specified in rather narrow terms. In moving up to higher command levels--i.e., up through ship or unit command level, to the task group command level, and on up to the fleet command level--these requirements become more diversified, broader in scope, and less quantitatively definitive in nature. At the individual ship level, a mission may be to screen a convoy, which would require the capability to perform certain functions such as steam to design capability; detect, locate, classify, and track submarines; engage submarines with anti-submarine armament; and provide own unit's command and control functions.¹¹ Though these operational capabilities are somewhat broad in nature, they can be broken down into more definitive functional requirements. Now compare this with the general mission of the overall fleet, which is to wage prompt and sustained combat at sea.¹⁵ (see Definition 21 of Table 1). The inference here must be to consider all possible eventualities, the occurrence of which can only be postulated and will be subject to wide disagreement among analysts and planners. Thus, the concept of readiness, being tied to mission requirements, will become more intangible in character as the level of organization moves up the command echelon hierarchy.

Sustainability is another factor that is closely tied in with readiness. In NWP-1, "Strategic Concepts of the U.S. Navy,"¹⁶ four distinct elements of Naval capability are identified that together provide the total force capability of a Navy. These are as follows:

- Force Structure--The numbers and types of organized units, active and reserve, of operating ships (or craft) and aircraft, and the facilities of the supporting base infrastructure.
- State of Modernization--The level of weapon system technology reflected in the components of the force structure.

- Readiness--The degree to which the operating units in the force structure are capable of performing the tasks for which they were designed and organized.
- Sustainability--The ability of operating units to continue to conduct naval operations over extended periods.

Note here that readiness and sustainability are considered as distinct elements. Since most, if not all, missions have some time element of performance implied, either explicitly or implicitly, readiness itself has a degree of time dependence implied. That is, readiness refers to the capability of an entity to perform its assigned missions over some specific, mission-dependent time period. Sustainability, on the other hand, refers to the capability of an entity to maintain some level of readiness over longer periods of time. For example, readiness might measure the ability of a task group to conduct antisubmarine warfare operations for some set time period--say, thirty days. Alternatively, sustainability would measure how long the task group would be able to maintain or exceed a prespecified threshold state of readiness. To this extent, sustainability is a highly time-dependent factor, while readiness is time-dependent only through the mission-dependent time period, which shall subsequently be referred to as the normal operating cycle for an organizational entity.

Based on the above discussion, the following expansion of the JCS definition of operational readiness (Definition 15 of Table 1) is proposed as a simple, usable definition of readiness that should satisfy the needs of both analysts and military planners.

Definition: Readiness is the degree to which an organizational entity is capable of performing, to its maximum potential, the missions for which it is organized during a normal operating cycle.

Inherent in this definition of readiness is the implication that an organizational entity's missions can be quantified to some extent. The degree to which quantification will be required will, of course, depend on the readiness measures being applied and the means by which these readiness measures are being estimated. Also, the maximum potential referred to is what the organizational entity would be capable of

performing in the best of cases. The actual performance capability typically degrades with time. That does not mean that the organizational entity cannot perform some or most of the missions it has been assigned. It is conceivable that by modifying its procedures, deployment, etc., the entity can still perform some missions, or some limited form of these missions. However, it could not carry them on for an extended period of time, or as effectively as it would otherwise. This degradation is expressed by the decrease in the degree of readiness.

For the remainder of this report, the above definition of readiness is assumed. When the term readiness is modified by an adjective such as material or personnel, the same definition is assumed to apply but only to the area enveloped by the modifier.

C. Criteria for Readiness Measures

The selection of an adequate measure of readiness will depend on the requirements of the particular problem under investigation. No one measure can satisfy the requirements of both planners and analysts at each and every level of command. The specific criteria for the selection of such a measure must consider such factors as the purposes for which the measure is to be used, the applicable echelons to be considered, and the availability of supporting data and evaluation tools. These factors, when taken together, will dictate the type of measure that will be most practical and feasible for the problem at hand. This does not imply that the selected measure will possess all the properties desired by a user. The ultimate desire for a continuous numerical measure that would be highly sensitive to small variations in, say, underlying resource availabilities may prove infeasible due to the lack of available supporting data or the tools to analyze these supporting data.

The types of measures fall generally within two different categories, depending on whether the underlying measurement system is ordinal-based or cardinal-based. According to Kaplan,¹⁴ an ordinal measurement system is "one which can assign a rank ordering of value to a set of different system states, while a cardinal measurement system gives us relative value information for different system states as well as rank ordering

information." An example of an ordinal-based readiness measure is the measure employed under the present Unit Status and Identity Reports (UNITREP) where an active Navy unit will report its C-rating (readiness status) as being either C-1 (Fully Ready), C-2 (Substantially Ready), C-3 (Marginally Ready), or C-4 (Not Ready). Although some quantitatively based guidelines are provided for determining the C-ratings for the overall unit and for each of the individual resource areas (personnel, equipment and supplies on hand, equipment readiness, and training), these determinations are still largely based on the unit commander's judgmental appraisal of the criticality of any deficiencies that may exist. The rank-ordering property of these measures is obvious from their definitions, and it should also be obvious that there is no substantive relative information value for the different readiness states for a given unit or even between different units. That is, the relative worth of improving one unit's status from, say, "marginally ready" to "substantially ready," as opposed to its status or another unit's status improving from "substantially ready" to "fully ready" cannot realistically be evaluated under that measurement system. At the other extreme, an example of a feasible cardinal-based readiness measure is the operational availability of a two-state system such as a simple radar unit that can either be operational or nonoperational. The operational availability of such a system can be defined as the probability that the system is operational and capable of failure-free operation for a specified period of time dictated--say--by mission requirements. There are numerous ways of computing this probability, some of which are based on empirical or theoretical estimates of the system's mean time between failures (MTBF) and mean time to repair (MTTR). This measure not only provides a rank ordering for readiness (that is, an operational availability of 0.9 is preferred to one of 0.8), but also provides a basis for evaluating relative worth by providing a continuous numerical measurement scale. That is, a system improvement option that increases the MTBF to such an extent that the operational availability increases from 0.7 to 0.8 would be preferred to a system improvement option that results in a decreased MTTR that only increases the operational availability to 0.75, assuming here that other factors, such as cost, remain relatively constant or are not significant determinants in the decision process.

The above two examples indicate a couple of interesting facets about readiness measures (and performance measures in general) that hold for the most part. Cardinal-based measures, especially those using a continuous measurement scale, are much more useful than ordinal-based measures, but the feasibility of obtaining meaningful cardinal-based measures decreases as the command echelon climbs higher up the ladder. At lower levels simple measures can be defined that easily reflect the effects of small changes in parameters. For example, consider the probability of detection (P_d) of a radar; a change in detection threshold will result in a measurable change in P_d (at an increase in false alarm rate, for sure). However, at higher levels such as those pertaining to the task group performance, such simple measures do not pertain. There are so many parameters impacting on that performance that individual consideration of individual parameters does not carry any substantial information. These parameters must be aggregated, and as a result the combined measure becomes relatively insensitive to any, even significant, perturbations of readiness parameters at lower echelon levels. To alleviate this insensitivity the readiness measure must change with each echelon of command to reflect the global performance capability representative of that echelon. More often than not, this change is also likely to result in a readiness measure that becomes more complex at the higher command echelons since the measure must encompass a large amount of information. This increase in complexity in turn requires more complex evaluation tools, which themselves create an increased demand for supporting data. Depending on the purpose of the given problem (be it assessing present readiness, estimating readiness in the near future, or predicting readiness in the distant future) and the availability of time and resources, there will exist a happy medium that provides a suitable tradeoff between the complexity of the required readiness measure, the sophistication of the required evaluation tools, and the demand for adequate supporting data. Finding this happy medium is, of course, a major problem facing analysts and planners in their efforts to address readiness, be it at the system, unit, task group, or fleet level of command.

D. Readiness Evaluation Techniques

Readiness evaluation techniques refer to any method that can be used to bridge the gap between the specification of the basic supporting input data (input resources) and the generation of values to be assigned to the selected readiness measure. In the selection of an appropriate readiness measure for a given problem, it is assumed that some consideration is given to the feasibility of using selected techniques as evaluation tools, even if for no other reason than to ensure that it is possible within the state of the art (or possibly with some anticipatory expansion of existing procedures) to go from the available (or to be generated) data inputs to an estimate of the readiness measure for the units or organizations involved. In some cases, the actual choice of an evaluation technique will, in essence, be dictated by the properties of the supporting data and readiness measure, while in other cases (and for the most part), a choice of alternative techniques will be available to the user. Evaluation techniques can generally be classified under one of four classes: empirical, theoretical, subjective, and combinatorial, where the last refers to some significant combination of the former three (virtually all evaluation techniques have some semblance of being combinatorial, but many fall predominantly under one of the first three headings). Empirical techniques are those that operate predominantly on observed or experimental data to establish functional relationships between selected resource factors and system performance parameters. An excellent example of this type of technique appears in the Navy Readiness Analysis System (NRAS) Methodology Study.¹⁶ The objective of that study was to examine the statistical and logical relationships among readiness resource and performance variables to establish a methodology or series of systematic techniques for computing readiness performance indices based on those relationships. Resource variables covered the areas of available personnel, training, equipment, and supply, while the readiness performance variables were the scores obtained during Refresher Training Operational Readiness Inspections (RFT or ORIs) for a sample of 82 Atlantic Fleet Destroyers. Test scores were obtained for 29 different functional areas, of which 21 are substantially related to the primary destroyer mission areas such as anti-air warfare,

antisubmarine warfare, and so on. Thus the basic performance data consists of 82 sets of 21 test scores, one set for each ship. Application of statistical techniques such as correlation analysis, principal component analysis, and factor analysis reduced the set of 21 scores down to a set of 3 factor scores. The factors were control procedures, casualty control procedures, and antisubmarine-warfare tactical communications. Each of these factors consists of weighted linear combination of a subset (different for each factor) of the basic 21 test parameters, and the factor scores obtained from applying the linear combinations to the basic test scores represent the readiness indices used in the study. Through multiple regression analysis, significant relationships were established between some of the variables representing the four resources of personnel, equipment, training, and supply. In a few cases, these relationships were contrary to expectations and would require further analysis to determine if such were truly the case. For many other resource variables, no significant relationships could be obtained; in some instances this could be explained, while in others further study would be required. Although the study did provide some positive results relative to the usefulness of the methodology, these were apparently not significant enough to warrant further study. One of the major drawbacks of empirical techniques such as this is that, although relationships may be established between input resources and output readiness variables, these relationships are for the most part mechanical and do not provide any sound explanatory basis for determining why the particular resource variables affect the readiness of a unit. Another disadvantage is that, in general, extrapolation of the relationships beyond the range from which they were derived often leads to highly erroneous and sometimes preposterous results.

Theoretical evaluation techniques provide a means of overcoming the drawbacks of empirical techniques, in that these techniques attempt to model the causal relationships between input resources and output values of performance--i.e., readiness. The types of models within this category range from some simple equation (that may be theoretically justified or simply implied by experimental data), on up through a rather

extensive analytical model consisting of many interrelated equations and logical relationships, to the ultimate in complexity, a highly detailed Monte Carlo computer simulation. One example of a theoretical model that falls somewhere in the middle of the two extremes mentioned is "A Continuous Time Markov Process Model of Naval Operational Readiness," by Tolins.¹⁷ This model considers the situation where a naval unit--say, a ship--can at any instant of time be in one of a finite set of discrete readiness states and that, as time goes by, the ship's readiness will change from one state to another. The model assumes that this time series of changes from one readiness state to another can be represented by a continuous-time Markov chain with stationary transition probabilities. That is, the probability of going from State *i* to State *j* is independent of the prior sequence of states it was in before moving into State *i*, and that this probability does not change with time. Equations are derived that provide estimates of the steady-state probabilities (i.e., the fraction of time) that a ship or a number of ships of the same class will be in each of the readiness states. The difficulty with this model, and theoretical models in general, is in justifying the applicability of the underlying assumptions--i.e., the stationary transition probabilities--or at least in showing a high degree of robustness of the assumptions--that is, that the model results are not significantly affected by fairly extensive violations of the assumptions. In order to circumvent this, fewer underlying assumptions are made that result in more complexity in the model structure. As experience has shown, as complexity increases, model usage decreases for many reasons, such as difficulties in obtaining and preparing adequate input data, increased educational requirements in the use of the model, longer computer running times, and less visibility of the causal relationships between inputs and outputs.

The third class of evaluation techniques consists of those that are based primarily on subjective judgements. These techniques can range from simple intuitional judgements such as are made in everyday life, on up through subjective decisions based on certain quantitative or qualitative bases, to the use of the Delphi approach, where a group of experts collectively apply their subjective judgements in a systematic manner to

establish logical relationships between resource inputs and performance outputs. The daily reporting of a unit's readiness status in the UNITREP system, which was mentioned previously in this chapter, is an example of a subjective evaluation technique. The unit commander is provided with some guidelines for determining a C-rating within a specific resource area. These may be quantitatively based. For example, under the personnel resource area, to be fully ready the unit must be assigned at least 95 percent of structured strength including at least 95 percent of petty officers for mission-essential ratings, along with other requirements. On the other hand, the guidelines may be qualitatively based, such as in the training resource area, where the requirement for full readiness is simply that no deficiencies exist in training that cause more than insignificant degradations in any of the primary mission areas.¹¹ Guidelines are also provided for determining overall combat readiness ratings, which are based on the existence of minor and/or major deficiencies that reduce the capability of the unit to perform effectively in one or more of its primary mission areas. The use of these subjective techniques, of course, introduce biases based on different individual judgements. In addition, as is possible with UNITREP reports, an appraiser subject to higher authority would normally have the tendency to bias his judgmental ratings in his own favor. Nevertheless, subjective evaluation techniques are the rule, rather than the exception, and the other types of evaluation techniques are usually called upon only when subjective techniques become suspect.

The combinatorial class of evaluation techniques includes those that either do not belong in any one of the other categories due to the lack of a predominant type of evaluation technique or because the technique is a much broader approach that utilizes several different evaluation techniques. Project MARIS¹⁸ was a large-scale, multiechelon effort to relate the operational capability, or readiness, of the Polaris weapons system to the basic logistic support system. This project relied basically on several models including a budget model, a three-echelon simulation model, and an analytical submarine readiness model. The use of these models was supported by numerous data analyses and other supporting

empirical and theoretical models. The approach was extremely complex and attempted to derive values for a single readiness index, the expected proportion of operational missiles available during a specified period of time. The simplicity of this index, be it a good measure of readiness or not, proved to exhibit an insensitivity to even fairly significant changes that occurred at lower echelons or subsystem levels. Thus, careful effort must be devoted to insuring that the readiness measure selected, and the technique used to evaluate readiness, are compatible in scope.

III TASK GROUP READINESS EVALUATION MODEL CONCEPT

A. General

The discussion on readiness concepts presented in the previous chapter provides the framework for establishing a task group readiness evaluation model concept. This chapter presents a formal description of such a model concept. In Section III-B, a detailed description of a readiness hierarchy structure for a task group is presented. This readiness hierarchy structure forms the backbone of the model concept. Section III-C then presents a detailed description of the evaluation model concept. This description defines the overall structure of the proposed model, details the required inputs, and provides the underlying mathematical algorithms that transform the inputs into an estimate of the overall readiness of a user-specified task group deployment.

B. Readiness Hierarchy

The readiness of a task group--that is, the capability of the task group to perform, to its full potential, the missions for which it is organized--is obviously dependent on the readiness states of the individual ships comprising the task group. Even when one or more of the ships in the task group are not in states of full readiness, the task group will be capable of performing some or all of its missions, although at a reduced level of performance than that attainable at full readiness. The flexibility of the task group to adjust to such situations through revised ship deployments and alternative operating procedures will depend, to a large extent, on the efficiency of command. Higher creativity at the command level will induce greater task group mission capability--that is, it will enhance the task group's readiness to perform its assigned missions. The ship readiness states themselves will be functions of numerous factors including the initial ship configurations (personnel, equipment, and supplies) at the time of the task

group formation, and various logistic support activities that are required for the duration of deployment of the task group. In order to establish relationships between these basic outfitting and support functions and the overall task group readiness, it is necessary to examine in detail the readiness hierarchy structure between these two levels of activity. Figure 2 presents a schematic diagram that provides a cross-sectional view of this highly complex structure. As will be described, there are numerous interactions and dependencies not indicated on the diagram, as well as missing branches of the overall tree structure that are omitted for purposes of clarity. At the top of the diagram is the box representing the task group, and at the bottom are boxes labeled as support factors that represent the attributes of the systems that establish the initial outfitting functions that the task group, as well as the various support functions required during the task group deployment. The boxes in between represent various intermediate levels in the hierarchy from the support function level to the task group level. In describing this readiness hierarchy, it is convenient to begin at the top, the task group level, and then work down to the bottom, the support function level.

1. Overall Task Group

A task group is formed and deployed for the purpose of conducting naval operations in support of some strategic or broad tactical mission for a specified, or possibly indefinite period of time. This mission requirement may be fairly broad, such as to initially maintain presence in a given area of the ocean, with the possibility of conducting counterforce or crisis control operations in case of a breakout of hostilities, or it may be more specific such as to conduct antisubmarine warfare operations in the Northwest Indian Ocean for a period of 90 days. In any case, the task group will be charged with performing a number of specific naval operational missions that are mandatory in the conduct of antisubmarine warfare, surface warfare, and so on. The overall readiness of the task group can be evaluated in terms of its readiness for conducting these operational missions. That is, given an

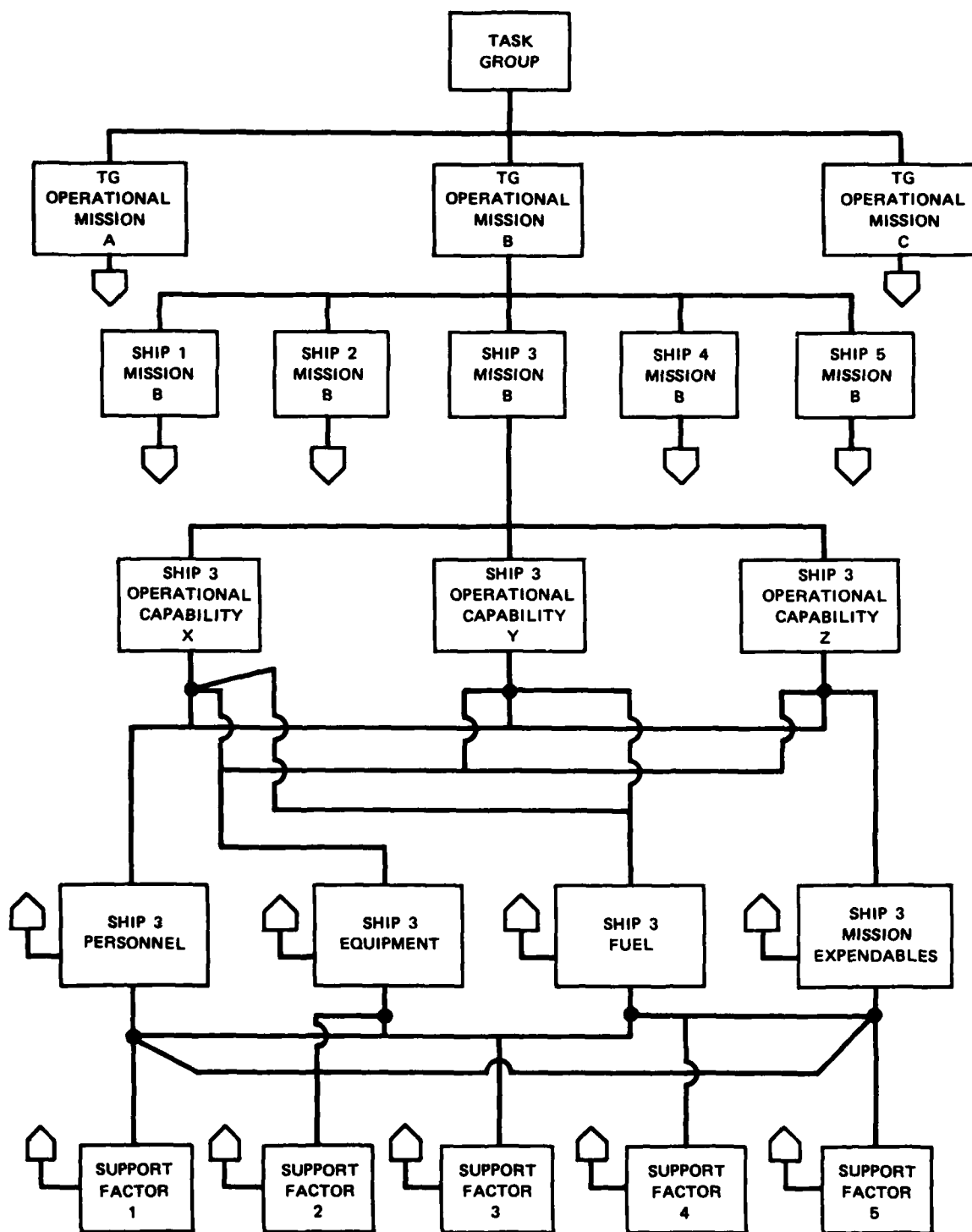


FIGURE 2 READINESS HIERARCHY STRUCTURE

expected amount of time that the task group will be performing each of the different operational missions during its period of deployment and the relative importance of each operational mission, then a weighted overall readiness estimate can be derived from individual operational mission readiness estimates, with the weighting factors being derived from the expected mission performance times. Where the requirements of the broad mission are subject to extraneous factors such as the possible outbreak of hostilities, then the requirements for conducting specific operational missions will be subject to a fairly high level of uncertainty. Nevertheless, some broad estimate (e.g., worst case, or most probable) can be made as to these requirements. In more specific cases, these requirements will be more predictable, resulting in a more straightforward evaluation of the overall readiness of the task group.

At the task group level, there may be an apparent dichotomous interpretation of the desired organization of the Task Group relative to the available ships assigned. To the task group commander, his readiness potential will be based on the potentials of the actual ships assigned. At the fleet command level or higher, this task group potential may be based on the potential of some standard configuration established for the particular mission of the Task Group, and any deviation from this configuration could result in a degradation of the task group readiness, at least as seen from the higher level of command. Thus, in evaluating task group readiness, care must be taken to ensure that the evaluation is performed with respect to the proper command echelon of concern.

2. Task Group Operational Missions

The next level down in the task group readiness hierarchy is that related to task group operational missions. The types of operational missions that a task group will be required to perform in support of its broader strategic mission will consist of a subset of the following list:

- Land Strike. Conduct search and strike operations against land-based targets.

- Surface Strike. Conduct search and strike operations against sea-surface-based targets.
- Subsurface Strike. Conduct search and strike operations against subsurface targets.
- Convoy Defense. Conduct screening operations in defense of a convoy.
- Amphibious Offense. Conduct Naval operations in support of an amphibious operation.
- Amphibious Defense. Conduct Naval supporting operations in defense of an amphibious operation.
- Barrier. Conduct antisubmarine operations to support a barrier operation.
- Blockade. Conduct Naval operations in support of a blockade.
- Search/Rescue. Conduct area search and rescue operations.
- Area Surveillance. Conduct air, surface and subsurface surveillance operations over a designated area.

The schematic diagram in Figure 2 indicates that the strategic mission for the sample task group requires the task group to perform operations in three different operational mission areas, generically denoted by A, B, and C. Each of these operational missions would be taken from the list above. The readiness of the task group to perform in an individual mission area will, of course, depend on the readiness of each individual ship of the task group to conduct its own mission requirements within the specific task group mission area. Although it can be assumed that all ships in the task group contribute to the task group's performance in each assigned mission area, it is also probable that for each mission area there is a relative ranking of importance of a ship's contribution to the performance of the overall mission requirements. For example, a destroyer may be more important than a guided missile frigate during antisubmarine operations, whereas the opposite could be the case during anti-air operations. Thus, individual ship readiness factors will impact on the task group readiness to a different degree, depending on the specific operational mission being evaluated.

3. Ship Missions

The next readiness level in the hierarchy structure represents the individual ship's capabilities to conduct operations in support of

each task group operational mission. The schematic diagram of Figure 2 indicates that the sample task group is composed of five ships, and the cross-sectional view of the readiness hierarchy structure at this level portrays the five ships contributing to the performance of the task group under Operational Mission B. The downward-pointing blank boxes under Task Group Operational Missions A and C imply a downward structural breakdown for these missions similar to that shown for Operational Mission B. The ship mission areas will coincide in nomenclature with the task group operational mission areas delineated in the previous subsection. However, the mission requirements imposed on each ship will, in general, differ in accordance with the individual ship's functions in support of the task group operational mission. The mission requirements for each ship will be delineated through the specification of the ship's required operational capabilities in support of that mission. The readiness of a ship relative to a specific mission will depend on the ship's readiness relative to each of the specified operational capabilities. However, the different operational capabilities will not have equal importance to the performance of the mission. For example, a destroyer conducting anti-submarine warfare operations will require an operational capability to conduct ship propulsion and navigation operations and another to conduct surface sonar operations, together with other operational capabilities. The importance of conducting operations under the first listed operational capability may only be, say, half the importance of the second operational capability. Thus, ship readiness factors for different operational capabilities impact on the ship's mission readiness to different degrees, depending on the specific mission being evaluated.

4. Ship Operational Capabilities

The next level in the hierarchy structure is represented by ship operational capabilities. The types of operational capabilities that ships will be required to perform in support of their different missions will consist of a subset of the following list, where these operational capabilities have been assembled under six major group headings:

(1) TDO--Target Detection Operations. Conduct operations to detect, identify, and locate targets.

- TDO-1. Conduct airborne detection operations.
- TDO-2. Conduct shipborne detection operations
- TDO-3. Conduct submarine-borne detection operations

(2) RO--Radiation Operations. Conduct operations to monitor radiation (electronic and acoustic) from enemy units and provide radiation deception against these units.

- RO-1. Conduct airborne radiation monitoring and deception operations
- RO-2. Conduct shipborne radiation monitoring and deception operations
- RO-3. Conduct submarine-borne monitoring and deception operations

(3) MSO--Mobility and Support Operations. Conduct operations to provide ship and aircraft mobility, own unit support, and support of special noncombat operations.

- MSO-1. Conduct ship propulsion and navigation operations
- MSO-2. Conduct amphibious vehicle operations
- MSO-3. Conduct aircraft operations
- MSO-4. Conduct meteorologic/oceanographic observations
- MSO-5. Conduct underwater recovery operations
- MSO-6. Conduct search and rescue operations
- MSO-7. Conduct mine countermeasure operations
- MSO-8. Conduct organic maintenance, supply, and administrative operations
- MSO-9. Conduct on-board training operations.

(4) EEO--Enemy Encounter Operations.

- EEO-1. Conduct air-to-air weapon operations
- EEO-2. Conduct air-to-surface weapon operations
- EEO-3. Conduct air-to-subsurface weapon operations
- EEO-4. Conduct surface-to-air weapon operations
- EEO-5. Conduct surface-to-surface weapon operations
- EEO-6. Conduct surface-to-subsurface weapon operations

- EEO-7. Conduct subsurface-to-surface weapon operations
 - EEO-8. Conduct subsurface-to-subsurface weapon operations
 - EEO-9. Conduct mine laying and retrieval operations
 - EEO-10. Conduct raiding party, UDT, and SEAL operations
 - EEO-11. Conduct armed boarding party operations.
- (5) SSO-Supply Support Operations. Conduct operations to maintain adequate supplies.
- SO-1. Conduct underway replenishment operations
 - SO-2. Conduct in-port replenishment operations.
- (6) CCO--Command and Control Operations. Conduct command, control, communications, and intelligence operations.
- CCO-1. Conduct command, control, communications, and intelligence operations for task group
 - CCO-2. Conduct command, control, communications, and intelligence operations for own unit
 - CCO-3. Conduct airborne communications relay operations.

At this level in the hierarchy structure, the interactions and dependencies previously mentioned enter the picture. In the diagram of Figure 2, Ship #3, in performing its requirements under Mission B, must be capable of operations under the generic operational capabilities X, Y, and Z. The paths from the boxes representing these operational capabilities to their associated upward-pointing blank boxes imply that each operational capability for this ship can also be a requirement for one or more alternative missions (in this case, A and/or C) assigned to that ship. Thus, if the schematic included the whole structure, and not just a cross section, then there would be a myriad of criss crossing lines (not even considering yet the additional interactions and dependencies at the lower levels of the hierarchy structure), and the diagram would become virtually incomprehensible.

The capability of a ship or attached air complement to perform in accordance with the requirements imposed for an operational capability will depend on the unit's readiness relative to each of a set of resource areas (personnel, equipment, etc.). The relative importance of each

resource area to a specific operational capability will differ among the resource areas, and the importance of a specific resource area will differ relative to alternative operational capabilities.

5. Unit Resource Areas

The next level of the readiness hierarchy structure consists of the unit resource areas. These resource areas represent a general breakout of a ship's resources into distinct and separately measurable readiness factors. In present Navy parlance, unit readiness is broken down into four major resource areas: personnel, equipment and supplies on hand, equipment operability, and training. Although this breakdown is convenient for a commander of a unit in assessing his present readiness, use of this breakdown for predicting future readiness, especially in terms relative to logistic support factors, will not prove rewarding. One difficulty is in determining what personnel factors fall under the heading of training readiness. Another factor is that equipment falls under two resource areas, one relating to physical availability and the other to operability, and it is difficult to analytically separate physical availability and operability. For instance, spare part availability would affect both equipment-and-supplies-on hand and equipment-operability resource areas, and it would be extremely difficult to decouple this relationship. Thus, for the purpose of this model concept, an alternative set of unit readiness resource areas is proposed. These are: personnel, equipment, fuel, and mission expendables. The personnel resource area will include such initial assignment factors as the overall strength, petty officer strength, and mission essential skill areas of the personnel assigned to the unit relative to that authorized, in addition to the deployment factors such as training opportunities, and the morale, health, and well-being of the assigned personnel while at sea. The equipment resource area simply combines the factors of the physical availability and operability of all equipment and, more emphatically, of all mission-essential equipment. The fuel resource area includes consideration of the availability of all fuels required for the performance of the required missions assigned to the unit. These will

include, depending on the type of unit, jet fuel, AVGAS, diesel fuel, and navy-distillate fuel. Similarly, the resource area of mission expendables includes those major end items such as ammunition and sonobuoys that are expended during the performance of related missions. Although the demand for these items will, to a great extent, be uncontrollable because it depends on the actions of uncontrollable factors such as the threat and the environment, readiness can be assumed related to an expected demand for these items under prevailing conditions. Unit readiness in each resource area will, in general, have an effect on the ship's readiness relative to many of the operational capabilities imposed on the ship in support of the alternative missions allocated to the ship. In the schematic of Figure 2, all resource areas for Ship #3 are portrayed as having an effect on each of the three operational capabilities imposed on the ship in support of Mission B, with the exceptions that Mission Expendables do not have an effect on Operational Capabilities X and Y, and Fuel does not have an effect on Operational Capability Z. The implied relationships of the resource areas for Ship #3 with other operational capabilities not shown on the diagram are indicated by the paths to the upward-pointing blank boxes. The readiness of a unit within each resource area will be a function of the various support factors that include the initial outfitting of the ship and its continued supply support during the period of deployment. Different support factors will relate to different resource areas, and although some commonality will exist, the impact of a support factor on the readiness of the unit in one resource area may be more or less pronounced than that on the readiness in another resource area.

6. Support Factors

The bottom level in the readiness hierarchy structure is the level representing the support activities that are the primary driving forces that impact on the readiness of the task group units in the various resource areas, and subsequently impact on the ultimate readiness of the task group in the performance of its overall mission. Table 2 provides a list of the primary support factors that have a direct

Table 2
UNIT RESOURCE AREAS VS PRIMARY SUPPORT FACTORS

Resource Area	Primary Support Factor
Personnel	Initial personnel availability Initial personnel supply provisioning Resupply factors On-the-job training opportunities Reinforcement factors
Equipment	Initial outfitting of equipment Initial spare-part and supply provisioning Reliability Maintainability Resupply factors
Fuel	Initial fuel provisioning Resupply factors
Mission Expendables	Initial provisioning Resupply factors

relationship with each of a unit's resource areas. Although there are probably numerous other such factors that could be considered in a more detailed breakdown, it is assumed that the factors listed are sufficient for the purpose of the evaluation model concept description presented in the subsequent sections of this chapter. These support factors will, of course, impact on the resource areas of each unit in the task group, as implied by the upward-pointing blank boxes attached to the support factor boxes of Figure 2. In many cases, the effects of a support factor on each of the units may be highly dependent. For example, the re-supply of ship fuel is conducted on an overall task group basis, and any shortage of ship fuel will affect all of the ships in the task group that require that type of fuel.

C. Readiness Evaluation Model

The conceptual model formulated to address the problem of evaluating the effects of variations of the basic logistic support activities on the expected readiness of Navy task groups is depicted schematically in Figure 3.* Down the center of the diagram, the various levels in the readiness hierarchy structure are indicated. The general flow of the model operations is depicted along the periphery. This begins with the specification of basic task group inputs which identify the overall task group mission requirements, task group configurations, and certain other selected performance requirements. A preestablished data base identifying the various intermediate requirements imposed on the individual ships of the task group, beginning with the ship missions and proceeding down to the unit resource areas, is then operated on to establish a basic set of requirements to be satisfied by the logistic support functions. A support factor model is then exercised to establish estimates of the expected readiness of each ship for the four identified resource areas. The model then goes through a series of computations that generate an estimate of the overall task group readiness that considers the interactive effects of the resource area readiness values on readiness at the

*Originally Figure 1, repeated here for the convenience of the reader.

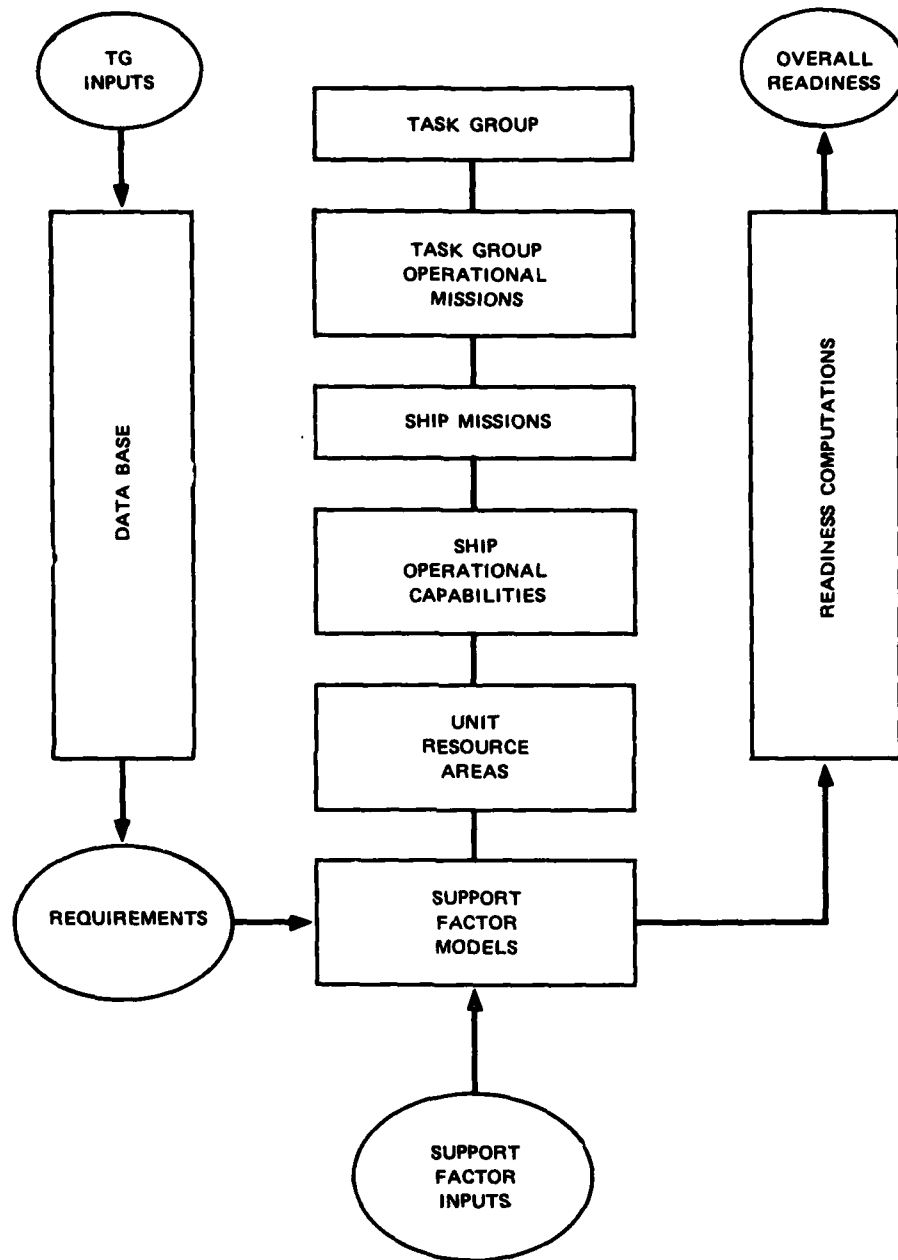


FIGURE 3 CONCEPTUAL MODEL STRUCTURE

various intermediate levels up through the hierarchy structure. The details of the various components of the model are described in the subsequent subsections.

1. Task Group Inputs

The task group inputs are to be specified by the user for each model exercise. These inputs are as follows:

- Operational mission types
- Estimated operational mission frequency during deployment
- Relative importance of each operational mission
- Maximum time to arrive on station
- Duration of deployment
- Deployment distance
- Task group configuration by ship type
- Speed of advance (while deploying)
- Data Base Overrides
- Readiness computational approach at each hierarchy level.

The operational missions assigned to the task group will be a subset of those listed in Section B-2 of this chapter and would be further defined through the specification of associated operational capabilities listed in Section B-4. While on deployment, the task group will conduct operations in performance of each of its operational missions, although not necessarily at the same frequency. That is, the task group may be predominantly oriented to one specific mission area--say, antisubmarine warfare--but will still be required to perform somewhat within other mission areas such as antiair warfare. It is also possible that, at times, the task group may be not performing an operational mission, such as when conducting training operations. One set of required inputs consists of the frequencies of expected performance within each operational mission area, including a special category reflecting nonoperational time. Another set of inputs required consists of those reflecting the relative importance of each operational mission. That is, specific tactical missions such as Surface Strike assume more importance than nontactical missions like Area Surveillance. The

deployment distance, the maximum time to arrive on station, and the planned duration of deployment are other inputs that will have a marked bearing on the task group's readiness. For a short period of deployment--say, 30 days--the task group will not be as critically dependent on logistic support functions, such as underway replenishment, as would be the case for periods of 90 days or more. The next set of inputs define the task group configuration--i.e., the number of ships by class that are assigned to the task group and the ship that serves as the command ship. For aircraft carriers, the numbers and types of squadrons assigned will also be specified. Also required is the speed of advance while the task group is deploying to its initial station. For the present model concept, readiness will be estimated in terms of the potential of the task group as configured, as opposed to estimating readiness in accordance with a standard design configuration. The possible degradation in readiness resulting from deviations from the standard design configuration can easily be established by computations external to the model. The next set of user inputs consist of the specification of any changes desired among the various data factors contained in the preestablished data base, described in the next section. Although the data factors in the data base will be established on the basis of standard Navy planning factors, there may be occasions to alter these values, either temporarily for the given model exercise or permanently for the given and future model exercises. This set of inputs will allow the user these options without requiring a complete revamping of the data base. The final set of user inputs is the specification of the particular readiness computation approach to be used at each hierarchy level. Three alternative approaches are allowed, and these are described later on in this discussion.

2. Data Base

The data base required for this model concept will consist of two sections: the Mission Requirements Section and the Support Requirements Section. The Mission Requirements Section provides the quantitative couplings between the various levels in the readiness hierarchy structure beginning with the task group operational mission level and proceeding

down to the unit resource area level. The Support Requirements Section contains the necessary numerical data that can be used to establish the quantitative load factors imposed on the various support systems for a specified task group deployment. These load factors, which will be dependent on the particular models used to relate the support system performance to individual unit readiness in the unit resource areas, will include such factors as initial outfitting requirements, deployment scheduling factors, supply, spare part, and fuel consumption rates, equipment operating hours, and so on. Although the data base will be quite extensive, its establishment will be a one-time task. Once established, it will be firmly embedded within the model. However, as mentioned previously, the user will have the option of making changes to specific data elements when desired.

a. Mission Requirements Section

The mission requirements section of the data base provides the quantitative input data that links the various levels of the readiness hierarchy structure together to establish the overall readiness of a postulated task group. These data are used to transform individual ship readiness estimates, starting at the unit resource area level, and proceeding on up to the task group operational mission level. This data base section is actually broken down into two subsections--those data linking the ship operational capabilities to the task group missions, denoted by MRS-A, and those linking the individual unit resource areas to the ship operational capabilities, denoted by MRS-B.

Table 3 presents a descriptive layout array of Subsection MRS-A. The task group operational missions are assembled across the top of the array and the ship types are assembled down the left side of the array. For each task group operational mission and each ship type, this data base contains the ship type importance factor relative to that mission, the required operational capabilities for the ship type, and the associated relative importance of these operational capabilities. For each task group operational mission, the ship type importance factors are specified in absolute terms--say, on a ranking scale from one to

Table 3
DESCRIPTIVE LAYOUT ARRAY: MISSION REQUIREMENTS SECTION -A

Task Group Operational Mission (OM)												
Ship Type (ST)	OM - 1			OM - 2			•	•	•	OM - N		
ST - 1	Ship Type Importance Factor			Ship Type Importance Factor			•	•	•	Ship Type Importance Factor		
	Ship Type Required Operational Capabilities	Operational Capability Relative Importance	Ship Type Required Operational Capabilities	Operational Capability Relative Importance	Ship Type Required Operational Capabilities	Operational Capability Relative Importance						
	Ship Type Required Operational Capabilities	Operational Capability Relative Importance	Ship Type Required Operational Capabilities	Operational Capability Relative Importance	Ship Type Required Operational Capabilities	Operational Capability Relative Importance						
ST - 2	Ship Type Importance Factor			Ship Type Importance Factor			•	•	•	Ship Type Importance Factor		
	Ship Type Required Operational Capabilities	Operational Capability Relative Importance	Ship Type Required Operational Capabilities	Operational Capability Relative Importance	Ship Type Required Operational Capabilities	Operational Capability Relative Importance						
	Ship Type Required Operational Capabilities	Operational Capability Relative Importance	Ship Type Required Operational Capabilities	Operational Capability Relative Importance	Ship Type Required Operational Capabilities	Operational Capability Relative Importance						
•	•			•			•	•	•	•		
	•			•						•		
	•			•						•		
ST - M	Ship Type Importance Factor			Ship Type Importance Factor			•	•	•	Ship Type Importance Factor		
	Ship Type Required Operational Capabilities	Operational Capability Relative Importance	Ship Type Required Operational Capabilities	Operational Capability Relative Importance	Ship Type Required Operational Capabilities	Operational Capability Relative Importance						
	Ship Type Required Operational Capabilities	Operational Capability Relative Importance	Ship Type Required Operational Capabilities	Operational Capability Relative Importance	Ship Type Required Operational Capabilities	Operational Capability Relative Importance						

ten--so as to provide a basis for determining the ship type's relative importance for that mission in terms of a specified task group configuration. In the model, the relative importance of each ship type for a task group operational mission would be determined by the ratio of the ship type's importance factor to the sum of the importance factors for all the ships in the task group configuration. The required operational capabilities for a ship type and a task group operational mission would be a subset of the operational capabilities listed in Section B-4 of this chapter. These operational capabilities will have an associated relative importance for the ship type's performance of its mission under the task group operational mission, and these are attached to the operational capabilities within the data base. Table 4 presents a sample of an MRS-A Section of a hypothetical data base that includes only two task group operational missions and three ship types. Note that a relative importance factor of zero implies that that ship does not contribute to the task group's performance of the specified operational mission, so there are no operational capabilities listed in that block of the data base.

For the purposes of this model concept, the unit resource areas have been broken down into sets of unit resource subareas, which are as follows:

- Personnel Resource Subareas
 - Operations Personnel (OP)
 - Maintenance Personnel (MP)
 - Other-Support Personnel (OSP).
- Equipment Resource Subareas
 - Propulsion and Navigation Systems Equipment (P&NSE)
 - Communications and Data Processing Systems Equipment (C&DPSE)
 - Surveillance Systems Equipment (SSE)
 - Weapons Systems Equipment (WSE)
 - Supply Systems Equipment (SPSE).
- Fuel Resource Subareas
 - Navy-distillate Fuel (NDF)
 - Diesel Fuel (DF)
 - Jet Fuel (JF)
 - Aviation Gas (AG).

Table 4

HYPOTHETICAL SAMPLE OF DATA BASE SECTION MRS-A ENTRIES *

	Land Strike		Blockade	
	10		6	
CVA	TDO-1	.12	TDO-1	.14
	TDO-2	.04	TDO-2	.10
	RO-1	.05	RO-1	.06
	RO-2	.03	RO-2	.06
	MSO-1	.12	MSO-1	.12
	MSO-3	.12	MSO-3	.12
	MSO-6	.02	MSO-8	.08
	MSO-8	.02	EEO-2	.12
	EEO-1	.11	SSO-1	.08
	EEO-2	.11	CCO-1	.12
	EEO-5	.04		
	SSO-1	.04		
	CCO-1	.12		
	CCO-3	.06		
DD	5		7	
	TDO-2	.12	TDO-2	.15
	RO-2	.12	RO-2	.07
	MSO-1	.18	MSO-1	.14
	MSO-6	.18	MSO-8	.08
	MSO-8	.16	EEO-5	.12
	SSO-1	.04	EEO-9	.12
	CCO-2	.20	EEO-11	.12
SSN	0		5	
	N/A		TDO-3	.20
			RO-3	.10
			MSO-1	.20
			MSO-8	.08
			EEO-7	.16
			SSO-1	.10
			CCO-2	.16

* For definitions of numerical entries, see Table 3.

● Mission Expendables Resource Subareas

- Air Delivered Missiles (ADM)
- Ship Delivered Missiles (SDM)
- Submarine Delivered Missiles (SUDM)
- Torpedoes (TS)
- Gun Ammunition (GA)
- Mines (MS)
- Depth Charges (DC)
- Sonobuoys (SO).

The data base inputs of Subsection MRS-B are specified in terms of these subareas.

Table 5 presents a descriptive layout array of Subsection MRS-B. The ship operational capabilities are assembled across the top of the array and the ship and aircraft squadron types are assembled down the left side of the array. For each ship operational capability and each unit type, this data base section indicates the relative importance of each of the unit resource subareas to the capability of the unit type to perform the necessary functions required by the listed operational capability. Table 6 presents a sample subsection of an MRS-B Section of a hypothetical data base. This subsection covers three operational capabilities and two unit types. Note that if an operational capability does not apply to a specific unit type, that block of the data base is left blank.

b. Support Requirements Section

The support requirements section of the data provides the quantitative inputs that are used to determine the load factors imposed on the various support systems during the task group's formation, deployment, and on-station phases of an operational mission. The exact nature of these inputs will depend on the support factor model(s) used to establish readiness estimates for ship types in each of the ship resource areas as functions of the effectiveness of the necessary support activities. For the support factor model discussed later in this chapter, the Support Requirements Data Base Section is broken down into two

Table 5
DESCRIPTIVE LAYOUT ARRAY: MISSION REQUIREMENTS SECTION-B

Ship/Aircraft Squadron Type (ST or AST)	Ship Operational Capabilities							
	TDO-1		TDO-2		CCO-3		Resource Subarea Relative Importance	
	Unit Resource Subareas	Resource Subarea Relative Importance	Unit Resource Subareas	Resource Subarea Relative Importance	Unit Resource Subareas	Resource Subarea Relative Importance		
ST-1								
•	•	•	•	•	•	•	•	•
•	•	•	•	•	•	•	•	•
•	•	•	•	•	•	•	•	•
ST-N								
	Unit Resource Subareas	Resource Subarea Relative Importance	Unit Resource Subareas	Resource Subarea Relative Importance	Unit Resource Subareas	Resource Subarea Relative Importance	Unit Resource Subareas	Resource Subarea Relative Importance
AST-1								
	Unit Resource Subareas	Resource Subarea Relative Importance	Unit Resource Subareas	Resource Subarea Relative Importance	Unit Resource Subareas	Resource Subarea Relative Importance	Unit Resource Subareas	Resource Subarea Relative Importance
•	•	•	•	•	•	•	•	•
•	•	•	•	•	•	•	•	•
•	•	•	•	•	•	•	•	•
AST-M								
	Unit Resource Subareas	Resource Subarea Relative Importance	Unit Resource Subareas	Resource Subarea Relative Importance	Unit Resource Subareas	Resource Subarea Relative Importance	Unit Resource Subareas	Resource Subarea Relative Importance
	•	•	•	•	•	•	•	•

Table 6

HYPOTHETICAL SAMPLE OF DATA BASE SECTION MRS-B ENTRIES*

			TDO-1	MSO-1		CCO-2	
CVA	N/A			OP	.20	OP	.30
				MP	.20	MP	.20
				OSP	.05	OSP	.20
				P&NSE	.20	P&NSE	.0
				C&DPSE	.15	C&DPSE	.30
				SSE	.0	SSE	.0
				WSE	.0	WSE	.0
				SPSE	.0	SPSE	.0
				NDF	.0	NDF	.0
				DF	.20	DF	.0
				JF	.0	JF	.0
				AG	.0	AG	.0
				ADM	.0	ADM	.0
				SDM	.0	SDM	.0
				SUDM	.0	SUDM	.0
				TS	.0	TS	.0
				GA	.0	GA	.0
				MS	.0	MS	.0
				DC	.0	DC	.0
				SO	.0	SO	.0
F-14 SQDN	OP	.20	N/A			OP	.30
	MP	.10				MP	.20
	OSP	.05				OSP	.20
	P&NSE	.20				P&NSE	.0
	C&DPSE	.05				C&DPSE	.30
	SSE	.20				SSE	.0
	WSE	.0				WSE	.0
	SPSE	.0				SPSE	.0
	NDF	.0				NDF	.0
	DF	.0				DF	.0
	JF	.20				JF	.0
	AG	.0				AG	.0
	ADM	.0				ADM	.0
	SDM	.0				SDM	.0
	SUDM	.0				SUDM	.0
	TS	.0				TS	.0
	GA	.0				GA	.0
	MS	.0				MS	.0
	DC	.0				DC	.0
	SO	.0				SO	.0

* For definitions of numerical entries, see Table 5. For definitions of other entries, see Section III-B-4 (Ship Operational Capabilities) and the Unit Resource Subarea list in the text of this section.

subsections: SRS-A consists of the support requirements data pertinent to the initial outfitting of a task group; SRS-B consists of the support requirements data pertinent to the actual deploying of a task group and the on-station phase of the deployment.

A descriptive layout array of data base subsection SRS-A is presented in Table 7. The specific data factors required in each of the four data blocks across the array are as follows (the specific categorical breakdowns of these inputs represent an initial level of detail for such a model as proposed here):

(1) Personnel Manning Requirements and Supply Allowances

- Authorized Manning
 - Officers
 - Petty Officers
 - Other Enlisted Personnel
- Mission Essential Skill (MES) Requirements
 - Number of Petty Officers requiring:
 - Operations Oriented MESs
 - Maintenance Oriented MESs
 - Other-Support Oriented MESs
 - Number of Other Enlisted Personnel requiring:
 - Operations Oriented MESs
 - Maintenance Oriented MESs
 - Other Support Oriented MESs
- Personnel Supply Allowances for:
 - Medical Supplies
 - Rations
 - Other Personal Supplies

(2) Major Equipment

- Numbers of Major Equipments required for:
 - Propulsion and Navigation Systems
 - Communications and Data Processing Systems
 - Surveillance Systems
 - Weapons Systems
 - Supply Systems

Table 7

DESCRIPTIVE LAYOUT ARRAY: SUPPORT REQUIREMENTS SECTION-A

Ship or Aircraft Squadron Type (ST or AST)	Data Base Requirements			
	Personnel Manning Requirements and Supply Allowances	Major Equipment, Spare Parts and Equipment-related Supply Allowances	Fuel Capacities Safety Levels and Critical Levels	Mission Expendables Initial Allowances
ST-1				
•	•	•	•	•
•	•	•	•	•
•	•	•	•	•
ST-N				
	Personnel Manning Requirements and Supply Allowances	Major Equipment, Spare Parts and Equipment-related Supply Allowances	Fuel Capacities Safety Levels and Critical Levels	Mission Expendables Initial Allowances
AST-1				
	Personnel Manning Requirements and Supply Allowances	Major Equipment, Spare Parts and Equipment-related Supply Allowances	Fuel Capacities Safety Levels and Critical Levels	Mission Expendables Initial Allowances
•	•	•	•	•
•	•	•	•	•
•	•	•	•	•
AST-M				
	Personnel Manning Requirements and Supply Allowances	Major Equipment, Spare Parts and Equipment-related Supply Allowances	Fuel Capacities Safety Levels and Critical Levels	Mission Expendables Initial Allowances

- Initial Spare Part Allowances for:
 - Propulsion and Navigation Systems
 - Communications and Data Processing Systems
 - Surveillance Systems
 - Weapons Systems
 - Supply Systems
- Spare Part Safety Levels for:
 - Propulsion and Navigation Systems
 - Communications and Data Processing Systems
 - Surveillance Systems
 - Weapons Systems
 - Supply Systems
- Spare Part Critical Levels for:
 - Propulsion and Navigation Systems
 - Communications and Data Processing Systems
 - Surveillance Systems
 - Weapons Systems
 - Supply Systems
- Initial Equipment Supply Allowances for:
 - Propulsion and Navigation Systems
 - Communications and Data Processing Systems
 - Surveillance Systems
 - Weapons Systems
 - Supply Systems
- Equipment Supply Safety Levels for:
 - Propulsion and Navigation Systems
 - Communications and Data Processing Systems
 - Surveillance Systems
 - Weapons Systems
 - Supply Systems
- Equipment Supply Critical Levels for:
 - Propulsion and Navigation Systems
 - Communications and Data Processing Systems

- Surveillance Systems
- Weapons Systems
- Supply Systems

(3) Fuel Capacities, Safety Levels, and Critical Levels

- Fuel Capacities for:
 - Navy-distillate
 - Diesel
 - Jet
 - Aviation Gas
- Safety Levels for:
 - Navy-distillate
 - Diesel
 - Jet
 - Aviation Gas
- Critical Levels for:
 - Navy-distillate
 - Diesel
 - Jet
 - Aviation Gas

(4) Mission Expendables Initial Allowance

- Initial Allowances of:
 - Air Delivered Missiles
 - Ship Delivered Missiles
 - Submarine Delivered Missiles
 - Torpedoes
 - Gun Ammunition
 - Mines
 - Depth Charges
 - Sonobuoys
- Safety Levels of:
 - Air Delivered Missiles
 - Ship Delivered Missiles
 - Submarine Delivered Missiles

- Torpedoes
- Gun Ammunition
- Mines
- Depth Charges
- Sonobuoys
- Critical Levels of:
 - Air Delivered Missiles
 - Ship Delivered Missiles
 - Submarine Delivered Missiles
 - Torpedoes
 - Gun Ammunition
 - Mines
 - Depth Charges
 - Sonobuoys

A descriptive layout array of data base subsection SRS-B is presented in Table 8. The specific data factors required in each of the four data blocks under each major heading across the array are as listed in the following subsections. These data factors are dependent on the applicable task group operational missions while on-station. During the actual deploying of the task group, it is assumed that standard procedures are followed, irrespective of the ultimate on-station missions, and hence a single set of these data factors can be embedded in the data base.

(1) Personnel Consumption Rates

- Daily Average Consumption Rates for:
 - Medical Supplies
 - Rations
 - Other Personal Supplies
- Fatigue Factors

(2) Equipment Operating Hours and Supply Consumption Rates

- Daily Average Operating Hours/Major Equipment for:
 - Propulsion and Navigation Systems
 - Communications and Data Processing Systems

Table 8
DESCRIPTIVE LAYOUT ARMY: SUPPORT REQUIREMENTS SECTION-B

Ship or Aircraft Squadron Type (ST or AST)	Data Base Requirements													
	Deployment Phase							On-Station Phase						
	Personnel Consumption Rates	Equipment Operating Hours and Supply Consumption Rates	Fuel Consumption Rates	Mission Expendables Consumption Rates	Personnel Consumption Rates	Equipment Operating Hours and Supply Consumption Rates	Fuel Consumption Rates	Mission Expendables Consumption Rates	Personnel Consumption Rates	Equipment Operating Hours and Supply Consumption Rates	Fuel Consumption Rates	Mission Expendables Consumption Rates	Personnel Consumption Rates	Equipment Operating Hours and Supply Consumption Rates
ST-1														
•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
ST-N														
•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
AST-I														
•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
AST-M														
•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
•	•	•	•	•	•	•	•	•	•	•	•	•	•	•

- Surveillance Systems
- Weapons Systems
- Supply Systems
- Daily Average Equipment Supply Consumption Rates for:
 - Propulsion and Navigation Systems
 - Communications and Data Processing Systems
 - Surveillance Systems
 - Weapons Systems
 - Supply Systems
- Daily Average Spare Part Consumption Rates for:
 - Propulsion and Navigation Systems
 - Communications and Data Processing Systems
 - Surveillance Systems
 - Weapons Systems
 - Supply Systems

(3) Fuel Consumption Rates

- Daily Average Fuel Consumption Rates for:
 - Navy-distillate
 - Diesel
 - Jet
 - Aviation Gas

(4) Mission Expendables Consumption Rates

- Daily Average Consumption Rates of:
 - Air Delivered Missiles
 - Ship Delivered Missiles
 - Submarine Delivered Missiles
 - Torpedoes
 - Gun Ammunition
 - Mines
 - Depth Charges
 - Sonobuoys

3. Task Group Support Requirements

This portion of the model is concerned with establishing the quantitative load factors that will be imposed on the various systems that provide support for the task group deployment being considered in the model exercise. These load factors will represent an accumulation of the various load factors generated by the individual ships in the task group, considering their initial outfitting requirements and average consumption rates/equipment operating hours while actually deploying and when on-station. These load factors are established separately for the three phases of a task group deployment: formation, deployment, and on-station.

a. Formation Load Factors

The task group formation load factors are simply summations of the various personnel manning requirements and supply allowances; equipment, spare part and supply allowances; fuel capacities, safety levels and critical levels; and mission expendables initial allowances, taken over the individual units of the task group. These load factors are broken down into the various categories contained in Section SRS-A of the data base, and are further categorized as being related to air, surface, or subsurface units. For each category, the summations take the following form:

$$FLF_{ju} = \sum_{i=1}^K X_{ij} I_i(u) \quad (1)$$

where

FLF_{ju} = Formation load factor for the j^{th} category in SRS-A for class u (u = air, surface or subsurface)

K = Number of units in the task group

- i_k = An indicator for the unit (ship or aircraft squadron) type of the k^{th} unit in the task group ($k = 1, \dots, K$)
- X_{ij} = Data base value of the j^{th} category for unit type i
- $I_i(u)$ = Indicator denoting if unit type i is in class u ($I_i(u) = 0$, no; $I_i(u) = 1$, yes).

For example, consider a simple task group containing one aircraft carrier with two F-14 squadrons, and one destroyer. In this case, $K = 4$ and i_1 = aircraft carrier, $i_2 = i_3$ = F-14 squadron, and i_4 = destroyer. Also, $I_{i_1}(\text{surface}) = I_{i_4}(\text{surface}) = 1$ and $I_{i_2}(\text{air}) = I_{i_3}(\text{air}) = 1$. All other values of $I_i(u)$ would be equal to zero. If the j^{th} category represents spare parts allowances for weapons systems, the X_{i_1j} would be the data base value of this category for an aircraft carrier.

b. Deployment Load Factors

The task group deployment load factors are the summations of the various consumption rates and equipment operating hours, taken over the individual units of the task group. These load factors are broken down into the various categories contained in Section SRS-B of the data base, and are further categorized as being related to air, surface, or subsurface units. For each category, the summations take the following form:

$$DLF_{ju} = \sum_{i=i_1}^{i_K} Y_{ij} I_i(u) \quad (2)$$

where

DLF_{ju} = Deployment load factor for the j^{th} category in SRS-B for class u (u = air, surface, or subsurface)

Y_{ij} = Data base value of the j^{th} category for unit type i

and all other variables are the same as defined in Section III-C-3-a, above.

c. On-Station Load Factors

The task group on-station load factors parallel the deployment load factors, although the form of the summations is more complicated due to the dependency of the load factors of the individual ships on the task group operational missions and their frequency of employment, on the average, over the planned duration of the task group deployment. These summations take the following form:

$$OLF_{ju} = \sum_{i=1}^{i_I} I_i(u) \sum_{m=1}^M f_m Z_{ijm} \quad (3)$$

where

OLF_{ju} = On-station load factor for the j^{th} category in SRS-B for class u (u = air, surface, or subsurface)

M = Number of task group operational missions identified in the data base

f_m = Estimated frequency of employment of the m^{th} operational mission during the task group deployment

Z_{ijm} = Data base value of the j^{th} category for unit type i conducting operations in support of operational mission type m

and all other variables are the same as defined in Section III-C-3-a.

4. Support Factor Inputs

The support factor inputs are inputs that indicate the values of various performance factors that represent the effectiveness of the various support systems in carrying out their intended functions. These are user-specified inputs for each model exercise and can be used to reflect the effects of variations in the composition and operational procedures of these systems. For example, if the user is interested in the

effect on a task group's readiness that would result from the implementation of postulated changes in the support activities, separate sets of these inputs would be used in model exercises to evaluate this, where one set of inputs would reflect the performance of the existing support activities and another set would reflect that of the modified support activities.

The specific inputs included in this data set will, of course, depend on the specific support factor model included in the readiness evaluation model concept as proposed here. In the description of the support factor model that follows, a sample expected value approach is described in some detail. The nature of the support factor inputs is given as they arise in the model description. Although a detailed description of these inputs could be presented here, it is felt that this would only add an element of confusion and detract from the understanding of the model concept.

5. Support Factor Model

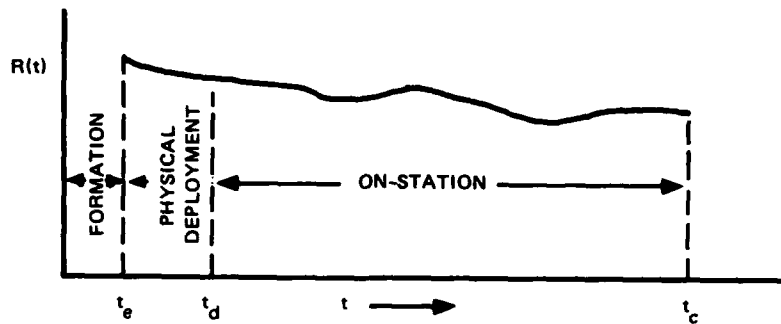
The support factor model described in this section is representative of the type of model that could be used to relate the effectiveness of logistic systems in support of a task group to the readiness states of individual ships within the various ship resource areas. The model components are first presented in generalized terms and then appended by a more detailed description of an expected value approach that could be used as an initial aggregated fulfillment of the function of the associated general model component. Implementation of such an aggregated model could be modular in nature so as to facilitate modification through the introduction of more complex algorithms to satisfy the requirements of the general model component functions.

The overall model structure can be envisioned as a matrix type structure, as depicted in Table 9, with the columns representing the three time phases of a task group's deployment (formation, physical deployment, on-station), and the rows representing the four major readiness resource areas (personnel, equipment, fuel, mission expendables), and an additional row to cover the deployment time factors. Each cell of the matrix then represents a separate model computation component.

Table 9
MODEL COMPUTATIONAL COMPONENT MATRIX STRUCTURE

Readiness Resource Area/Deployment Time Factors	Deployment Phase		
	Formation	Physical Deployment	On-Station
Personnel Readiness Resource Area	Personnel/Formation Computational Component	Personnel/Deployment Computational Component	Personnel/On-Station Computational Component
Equipment Readiness Resource Area	Equipment/Formation Computational Component	Equipment/Deployment Computational Component	Equipment/On-Station Computational Component
Fuel Readiness Resource Area	Fuel/Formation Computational Component	Fuel/Deployment Computational Component	Fuel/On-Station Computational Component
Mission Expendables Readiness Resource Area	Mission Expendables/Formation Computational Component	Mission Expendables/Deployment Computational Component	Mission Expendables/On-Station Computational Component
Deployment Time Factors	Deployment Time Factors/Formation Computational Component	Deployment Time Factors/Deployment Computational Component	Not Applicable

The general flow of computations would be from top to bottom within a column and then proceeding to the top of the next column. However, for descriptive clarity, it is convenient to discuss the complete computations for a major readiness resource area and the deployment time factors from the formation phase through the on-station phase. For each major readiness resource area there is a set of subareas--e.g., under the personnel readiness resource area, there are three subareas denoted as operations, maintenance, and other-support, and the computations are further broken down to the categories of air, surface, and subsurface units. However, for each subarea and unit-type breakdown of a given resource area, the computational procedures are identical. Although the computational procedures used for the different resource areas are varied, there is a general theme that is common to all of these (exclusive of the deployment time factors). This general theme infers the establishment of a readiness function for the particular resource area (actually for each subarea and unit-type breakdown of a resource area). The formation phase computations establish an initial embarkation value for this function. The physical deployment phase computations modify this value to account for changes that occurred while the task group was deploying to its intended at-sea deployment station. The on-station phase computations then establish the values of this readiness function for the duration of the task group's time on-station. The final output of the support factor model, for the particular subarea and unit-type breakdown of a major resource area, is the average value of this readiness function over the duration of the task group's time on-station. Schematically, this can be represented by the following diagram, where $R(t)$ denotes the readiness function, t_e the time of embarkation, t_d the time of arrival on station, and t_c the time of completion of the task group's time on-station:



The average readiness, \bar{R} is then given by the integral of $R(t)$ from t_d to t_c . That is,

$$\bar{R} = \int_{t_d}^{t_c} R(t)dt \quad (4)$$

With respect to the above diagram, there is one modification that should be mentioned here. The actual value of t_d used in the integral of Eq. (4) will not necessarily coincide with the task group's arrival on-station. That is, if the task group arrives on-station prior to its scheduled time--say, t_s --then the lower limit in the integral would be t_s and not t_d . On the other hand, if the unit arrives on-station after its scheduled time, the lower limit of the integral would still be t_d , but the task group would assume a zero readiness value for the time period from t_s to t_d . This period of zero readiness would then carry on up through subsequent computations external to this support factor model.

With this background, the description of the support factor model now proceeds to the individual rows of the model computational component matrix structure shown previously in Table 9.

a. Personnel Readiness Resource Area

The personnel readiness resource area is subdivided into three subareas: operations, maintenance, and other support. As previously mentioned, the computations are also performed separately for personnel assigned to the different unit types (air, surface, subsurface). Thus, one set of the following described computations would be performed for each subarea/unit-type combination. In the discussion that follows, the term "personnel readiness" refers to just one such combination and not to the personnel readiness resource area as a whole.

The personnel readiness function, $R_p(t)$, selected for this model concept is represented as follows:

$$R_p(t) = P_a(t) \cdot P_t(t) \cdot P_m(t). \quad (5)$$

$P_a(t)$ represents a personnel availability function that relates assigned strength to authorized strength, taking into account the three categories of officers, petty officers, and other enlisted. $P_t(t)$ represents a training efficiency function that relates assigned mission essential skill strengths to required mission essential skill strengths and also considers effects on on-the-job training opportunities while at sea. $P_m(t)$ represents a morale function that considers such factors as personnel supply deficiencies, time-at-sea degradations, and operational mission fatigue effects. Each of these component functions ranges from zero to one, so that the readiness function $R_p(t)$ itself will also range from zero to one.

The manner by which these functions are evaluated under the expected value approach is described in the following subsections.

1) Formation Phase

The expected value approach assumes that there exists Navy-wide data on the availability of officers, petty officers, and other enlisted men broken down into the various subcategories considered in

this model concept. These can be assumed to carry on down to the assignment of personnel to the task group, or could be modified by a criticality factor (presumably upward) that reflects a priority given to operational forces. Regardless, the model assumes as input the values of the availability of officers, petty officers, and other enlisted men. If we let a_o , a_{po} , and a_{oe} denote these respective availabilities, and recalling that t_e denotes the time of embarkation, then

$$P_a(t_e) = a_o a_{po} a_{oe}. \quad (6)$$

For subsequent computations, the actual assigned strengths of the personnel in each category at time of embarkation will also be required. These are given as follows:

$$AS_o(t_e) = a_o RS_o \quad (7)$$

$$AS_{po}(t_e) = a_{po} RS_{po} \quad (8)$$

$$AS_{oe}(t_e) = a_{oe} RS_{oe} \quad (9)$$

where AS denotes assigned strength, RS required strength, and the subscripts refer to the associated personnel categories as given for the availabilities. The values of the RS variables were previously computed as formation load factors (see Section III-C-3-a). Under the same reasoning as given above, it is assumed that input values exist for the availabilities of mission essential skill personnel in each category, and these are denoted by m_o , m_{po} , and m_{oe} . Furthermore, it is assumed that there can be determined an input training efficiency factor, $E_t(t_e)$, that is a reflection of the training efficiency (on a scale from zero to one) of personnel to be assigned to a task group. Then at time of embarkation, the training efficiency function is given as follows:

$$P_t(t_e) = m_o m_{po} m_{oe} E_t(t_e). \quad (10)$$

For subsequent computations, the actual assigned strengths of mission essential skilled personnel in each category at time of embarkation will also be required. These are given as follows:

$$AM_o(t_e) = m_o RM_o \quad (11)$$

$$AM_{po}(t_e) = m_{po} RM_{po} \quad (12)$$

$$AM_{oe}(t_e) = m_{oe} RM_{oe} \quad (13)$$

where AM denotes assigned mission essential skilled personnel, RM required mission essential skilled personnel, and the subscripts refer to the associated personnel categories. The values of the RM variables were previously computed as formation load factors.

Thus, at time of embarkation, the value of the readiness function is computed as follows:

$$R_p(t_e) = P_a(t_e) \cdot P_t(t_e) \cdot P_m(t_e) \quad (14)$$

where $P_a(t_e)$ and $P_t(t_e)$ are as given in Eq. (6) and (10), respectively, and $P_m(t_e)$ is specified as input. Here, and in subsequent computations, the time variables will be assumed specified in days. Another point to bring up before proceeding is that the morale function is the same for each of the three subareas of operations, maintenance, and other support. Thus this function is only computed once for each phase.

2) Physical Deployment Phase

During the actual deploying of the task group to its initial station, the value of the readiness function, or more specifically the values of the components of the readiness function, will be subject to variation. From embarkation until arrival on-station, the interim values of the readiness function are not directly of concern in this model, other than their ultimate effect on the value of this function at time of arrival on station.

The personnel availability function will be affected by both personnel losses, due to medical or personal problems, and personnel gains through reinforcement. In the expected value approach, losses and gains are assumed to be linear functions, with the rates specified as inputs. If t_d denotes the time of arrival on-station, then the personnel availability function will assume the following value at time of arrival on station:

$$P_a(t_d) = \left[\left\{ 1 + (g_{od} - d_{od})(t_d - t_e) \right\} \frac{AS_o(t_e)}{RS_o} \right]$$

$$\left[\left\{ 1 + (g_{pod} - d_{pod})(t_d - t_e) \right\} \frac{AS_{po}(t_e)}{RS_{po}} \right]$$

$$\left[\left\{ 1 + (g_{oed} - d_{oed})(t_d - t_e) \right\} \frac{AS_{oe}(t_e)}{AS_{oe}} \right] \quad (15)$$

where the AS and RS variables are as defined previously and the d and g factors denote the respective input daily loss and gain rates with the subscripts od, pod, and oed referring to officers, petty officers, and other enlisted, respectively (with the d denoting deployment phase). If,

in the computations of Eq. (15), $P_a(t_d)$ goes below zero or above unity, the $P_a(t_d)$ assumes the respective limiting value.

The loss and gain rates will also affect the mission-essential-skill components of the training function in the same manner as above. In addition, the training efficiency factor will also be modified to reflect the effects of on-the-job training opportunities, stemming both from on-the-job performance and additional time devoted to training while at sea. For the present model, three support factor inputs will be required: T_{tm} , the average daily amount of skill-related time required to maintain training efficiency; T_{td} , the average daily amount of skill-related time available during the present deploying of the task group; and k_t , a coefficient that reflects the proportional change in efficiency per unit time of deviation from T_{tm} . With these inputs the training efficiency function will assume the following value at time of arrival on station:

$$P_t(t_d) = \left[\left\{ 1 + (g_{od} - d_{od})(t_d - t_e) \right\} \frac{AM_o(t_e)}{RM_o} \right] \left[\left\{ 1 + (g_{pod} - d_{pod})(t_d - t_e) \right\} \frac{AM_{po}(t_e)}{RM_{po}} \right] \left[\left\{ 1 + (g_{oed} - d_{oed})(t_d - t_e) \right\} \frac{AM_{oe}(t_e)}{RM_{oe}} \right] \left[\left\{ 1 + k_t \frac{T_{td} - T_{tm}}{T_{tm}} (t_d - t_e) \right\} E_t(t_e) \right] \quad (16)$$

where $P_t(t_d)$ is, like $P_a(t_d)$, bounded below by zero and above by unity.

The morale function will be degraded due to possible supply shortages and also through extended periods of time at sea. Some

additional factors that could degrade morale such as command deficiencies and overall personnel shortages are reflected in the personnel availability function, and thus they are not compounded through inclusion again in the morale function. Therefore, the morale function is itself broken down into four degradation components, three for supply deficiencies (medical, rations, other personnel supplies) and one for time-at-sea degradations, and its initial embarkation value, $P_m(t_e)$. The supply components will each assume a value of unity as long as the amount of supplies in that class, being depleted by application of the deployment consumption rate load factors, remains above the safety level. Once the amount of supplies in a class drops below the safety level, that supply morale component will begin to degrade linearly and assume a value of zero when, and if, the critical level for that supply class is reached. Whenever replenishment of those supplies occurs, the amount of available supplies is increased by the replenishment amount, and the supply morale component then assumes its appropriate value considering this increased amount of supplies. This can be represented schematically with the use of Figure 4.

The initial level of supplies will be determined through the use of support factor input-specified supply availabilities for each of the three classes as applied to the task group supply allowances previously computed as formation load factors. In the figure, the supply level at time of embarkation is above the safety level, so the morale component is unity until consumption depletes supplies below the safety level. At this point, the supply morale component decreases linearly until a replenishment occurs. The replenishment occurs before the critical supply level is reached, so the component does not reach zero. Since the amount of the replenishment raises the amount of supplies above the safety level, the component again assumes a value of unity. The next depletion cycle allows the supply level to drop below the critical level, so the component assumes the value of zero until the next replenishment occurs. This cycling continues until the time of arrival of the task group on-station. The values of $m_i(t_d)$ would then be used in computing the value of the morale function at this point in time, where the subscript i generically would be m for medical supplies, r for rations,

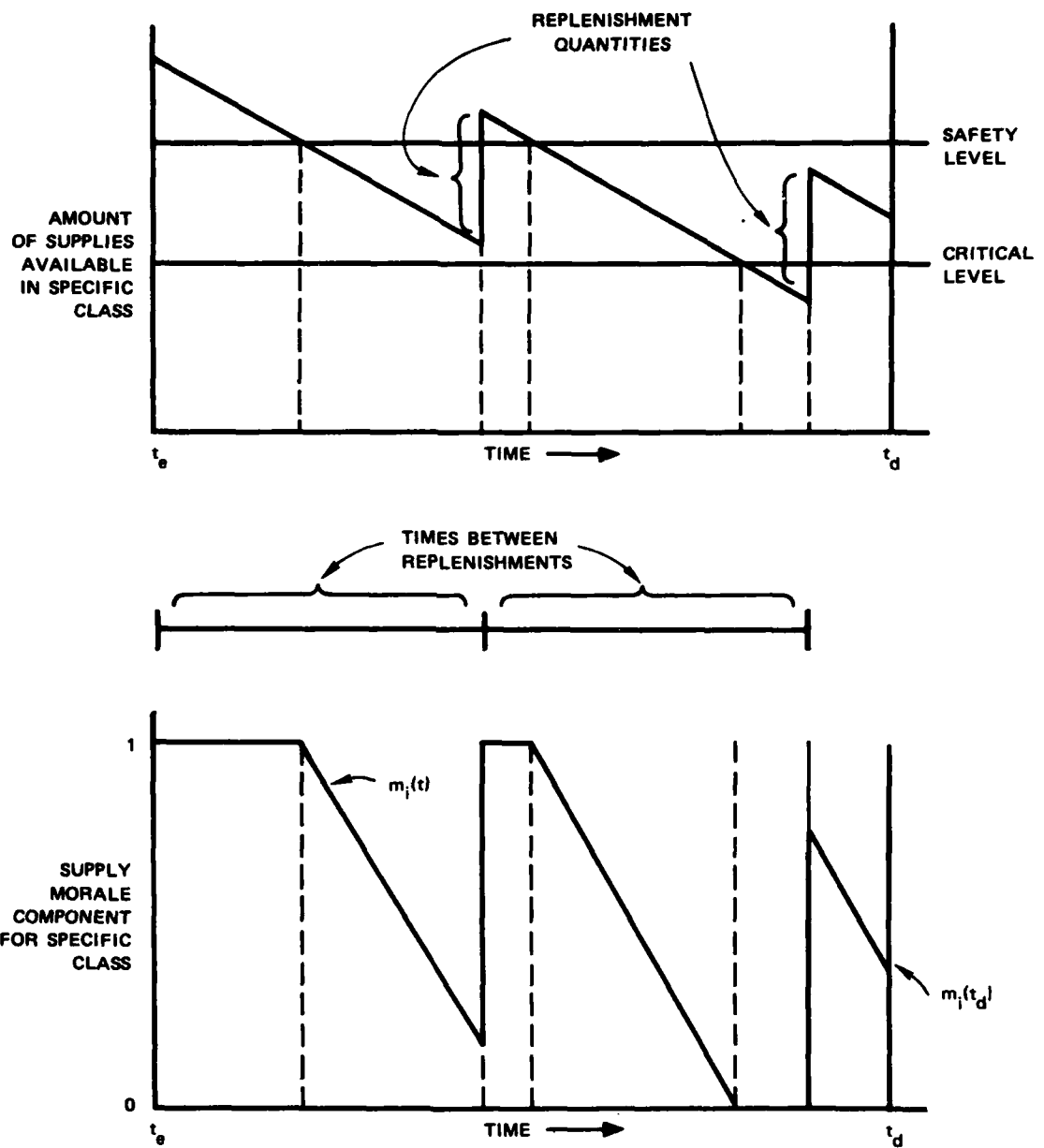


FIGURE 4 SUPPLY MORALE COMPONENT CONSTRUCTION DIAGRAM

and o for other personnel supplies. Of course, Figure 4 is quite exaggerated for consideration of the physical deployment phase, since it is highly unlikely that supply levels will reach the critical level or even the safety level during this phase of the deployment. However, they do indicate the construction of the supply morale components. This approach will also be used for the on-station phase computations where these more critical depletions could be realized.

The time-at-sea morale component assumes a linear degradation in morale as the time at sea increases. During deployment, a data base input listed under the heading of fatigue factor (f_d) represents the slope of this linear degradation. Thus, the time-at-sea morale component $m_t(t_d)$ at time of arrival on station is given as follows:

$$m_t(t_d) = f_d(t_d - t_e). \quad (17)$$

At time t_d , then, the morale function is given as follows:

$$P_m(t_d) = m_m(t_d) \cdot m_r(t_d) \cdot m_o(t_d) \cdot m_t(t_d) \cdot P_m(t_e). \quad (18)$$

The personnel readiness function at time t_d , the beginning of the task group's time on station, is computed as follows:

$$R_p(t_d) = P_a(t_d) \cdot P_t(t_d) \cdot P_m(t_d) \quad (19)$$

3) On-Station Phase

The manner by which the personnel readiness function is computed at each time point t during the task group's time on-station is the same as that used in the physical deployment phase, with the exception that t_e is replaced by t_d , t_d is replaced by t , the values of

the AS and AM factors as well as E_t at time t_d are as given by the modified numerators of the respective components in Eqs. (15) and (16), and the various load factors and other deployment specified data base and support factor inputs are for the on-station phase in lieu of the physical deployment phase. Due to the nature of the components of the personnel readiness function, it will probably be extremely difficult to establish a closed-form representation of the function throughout the duration of time on-station. Thus, it can be assumed that the integration of the function, as indicated in Eq. (4), will be performed using numerical integration techniques. In this case, values for the personnel readiness function would have to be computed at discrete time points during the interval from time of arrival on-station until completion of the task group's stay on-station.

b. Equipment Readiness Resource Area

The equipment readiness resource area is subdivided into five subareas: propulsion and navigation systems, communications and data processing systems, surveillance systems, weapons systems, and supply systems. The computations are also performed separately for equipments aboard the different unit types (air, surface, subsurface). Thus, one set of the following described computations would be performed for each system subarea/unit-type combination. In the discussion that follows, the term "equipment readiness" refers to just one such combination and not to the equipment readiness resource area as a whole.

The equipment readiness function, $R_e(t)$, selected for the model concept is represented as follows:

$$R_e(t) = E_o(t) \cdot E_s(t) \cdot E_{sp}(t). \quad (20)$$

$E_o(t)$ represents an equipment operability function that relates the available operable equipments to required operable equipments. $E_s(t)$ represents an equipment supply function that relates available equipment-oriented supplies (excluding spare parts) to equipment-oriented supply

allowances. $E_{sp}(t)$ is an equipment spare part function that relates available spare parts to spare part allowances. Each of these component functions ranges from zero to one, so that the readiness function $R_e(t)$ itself will also range from zero to one.

The manner by which these functions are evaluated under the expected value approach is now described in the following subsections.

1) Formation Phase

The expected value approach assumes that there exists Navy-wide data on the availability of equipment, equipment-oriented supplies, and spare parts, broken down into the various subcategories considered in this model concept. These can be assumed to apply to the outfitting of a task group or could be modified by a criticality factor (presumably upward) that reflects a priority given to operational forces. If we let a_e , a_s , and a_{sp} denote these respective availabilities, then at a time of embarkation, the equipment readiness function is given as follows:

$$P_e(t_e) = a_e a_s a_{sp} . \quad (21)$$

For subsequent computations, the actual numbers or amounts of equipments, supplies, and spare parts at time of embarkation will also be required. These are given as follows:

$$AE_e(t_e) = a_e RE_e \quad (22)$$

$$AE_s(t_e) = a_s RE_s \quad (23)$$

$$AE_{sp}(t_e) = a_{sp} RE_{sp} . \quad (24)$$

2) Physical Deployment Phase

During the actual deploying of the task group to its initial station, the values of the components of the equipment readiness function will be subject to variation since equipments will be operating and failures will occur, repairs will be made and spare parts depleted, equipment-oriented supplies will also be depleted, and replenishments may occur. As with the personnel readiness functions, the values of the components at time of arrival on-station are the main concern in this model, and the interim values are not in themselves required.

The equipment operability function will be affected by equipment failures, and subsequent repair completions and replenishments. In addition to the time between replenishments and major end item replenishment quantities, additional support factor inputs required are the equipment mean times to failure, for both on-board repairable failures (t_r) and non-repairable failures (t_{nr}), and mean repair times for on-board repairable failures (t_m) for each of the equipment system categories. The mean times to failure are converted to associated failure rates, denoted respectively by f_r and f_{nr} , and are computed as follows:

$$f_r = \frac{1}{t_r}$$

$$f_{nr} = \frac{1}{t_{nr}} \quad (25)$$

The procedure for computing the number of operating systems available each day $AE_e(t)$ is iterative in nature and is given by the following equation:

$$\begin{aligned} AE_e(t) = & AE_e(t-1) - f_{nr} \circ AE_e(t-1) - f_r(1-f_{nr}) \circ AE_e(t-1) \\ & + f_r(1-f_r) \circ AE_e(t-1-t_m) + n_r(t-1) \end{aligned} \quad (26)$$

where o_e is the daily operating hours/equipment during the physical deployment phase of the deployment, which is contained in the SRS-B subsection of the data base, and $n_r(t-1)$ is the number of equipments supplied if a replenishment occurs on day $(t-1)$. Otherwise, $n_r(t-1)$ is zero. In the above equation, the first term on the right-hand side denotes the number of operating equipments available at the beginning of the previous day $(t-1)$. The initial value, $AE_e(t_e)$, is computed in accordance with Eq. (22). The second term is the number of on-board nonrepairable failures occurring on the previous day, and the third term is the number of on-board repairable failures occurring on that day. The fourth term represents the number of repaired equipments that are brought back into service during the previous day. The value of t_m used in the equation is specified in whole days, and this represents a conversion of the input value if not specified in such terms. For the first t_m days, this fourth term is equal to zero, since the model assumes that on day t_e all available equipments are operational. The last term represents replenishment, if occurring on the previous day, of both initially unavailable equipments and for subsequent on-board nonrepairable failures. For the deployment phase, the iterative computations are performed up to time t_d , the time of the task group's arrival on-station. The equipment operability function on day t_d is then computed as follows:

$$E_o(t_d) = \frac{AE_e(t_d)}{RE_e} . \quad (27)$$

The procedure for computing the values of both the equipment supply function $E_s(t_d)$ and the equipment spare part function $E_{sp}(t_d)$ is the same as used to compute the supply morale component as described in the previous section, using the appropriate supply level and consumption rate load factors computed as in Eq. (2) for the applicable equipment system type. That is, these functions are unity as long as the supply level is above the safety level, and degrade linearly to zero as the supply level decreases down to and below the critical level. They increase only when replenishments occur. The procedure is used

to compute the applicable supply levels at time t_d , given by $AE_s(t_d)$ and $AE_{sp}(t_d)$, and the applicable functions are then computed as follows:

$$E_s(t_d) = \frac{AE_s(t_d)}{RE_s} \quad (28)$$

$$E_{sp}(t_d) = \frac{AE_{sp}(t_d)}{RE_{sp}} \quad (29)$$

The equipment readiness function at time t_d , the time of arrival of the task group on-station, is then computed as follows:

$$R_e(t_d) = E_o(t_d) \cdot E_s(t_d) \cdot E_{sp}(t_d) \quad (30)$$

where the three factors on the right-hand side are given by Eqs. (27), (28), and (29), respectively.

3) On-Station Phase

As discussed in the previous section for the personnel readiness function during the on-station phase, the procedure used to compute the equipment readiness function during this phase is the same as that used during the physical deployment phase. Of course, the various load factors and other data base and support factor inputs used in the computations are those for the on-station phase. A numerical integration procedure will also be required, so that the equipment readiness function will have to be computed at discrete time points during the interval from time of arrival on-station until completion of the task group's stay on-station.

c. Fuel Readiness Resource Area

The fuel readiness resource area is subdivided into four subareas: Navy-distillate, diesel, jet, and aviation gas. As with the other resource areas, the computations are performed separately for the different unit types (air, surface, subsurface). Thus a fuel readiness function will be computed for each subarea/unit-type combination. Since fuel is simply a supply class, the readiness functions have only one component (fuel availability) and the procedure for computing these is the same as that described for the equipment supply function in the previous section. Beginning with an initial fuel supply availability (a support factor input), fuel is depleted through consumption and replenished at periodic intervals. As long as the fuel available remains above the safety level, the fuel readiness functions $R_f(t)$ is unity. When the fuel drops below the safety level, the fuel readiness function decreases linearly to zero as the supply level decreases down to and below the critical level, rising only when a replenishment occurs. One special addition is that if the fuel level for the surface or subsurface categories drops below the critical level during the deployment phase, the task group will be assumed to remain stationary, with essentially no fuel consumption in the categories, until a replenishment occurs. This lack of movement will cause an extension of the expected arrival time on-station (t_d) and hence impose recalculation of the personnel and equipment readiness functions for the deployment phase. (Recall that all deployment phase computations are done before any on-station calculations are performed, so these deployment phase delays would not impose any recalculation for the on-station phase.) During the on-station phase, fuel depletion below the critical level will result in zero readiness and would be picked up in the integration of the fuel readiness function, and thus needs not be separately treated. As in the other cases, the integration of the readiness function, as indicated in Eq. (4), would be by numerical techniques due to the discrete jumps that would occur at replenishment time.

d. Mission Expendables Readiness Resource Area

The mission expendables readiness resource area is subdivided into eight subareas: air delivered missiles, ship delivered missiles, submarine delivered missiles, torpedoes, gun ammunition, mines, depth charges, and sonobuoys. As with the other resource areas, the computations are also performed separately for the different unit types (air, surface, subsurface). Thus a mission expendables readiness function will be computed for each subarea/unit-type combination. Since mission expendables are simply subclasses of supply, the readiness functions $R_m(t)$ have only one component (mission expendables availability), and the procedure for computing these functions is the same as for the other supply-related functions discussed in the previous section, with the exception that zero readiness during the deployment phase does not affect the time of arrival on-station.

e. Deployment Time Factors

The deployment time factors of concern are the time of embarkation, the time of arrival of the task group on-station, and the time of the task group's completion of its on-station stay. The time of embarkation, t_e , is dependent on various outfitting rates and the numbers and amount of personnel, equipment, supplies, and fuel that will ultimately be available to the task group on embarkation. In the present model concept, it is assumed that all major equipments and personnel are on-board ship at time zero, or will be on-board by the time supplies are loaded and the necessary fuel has been pumped on-board. The time to embarkation is then the maximum of the times required to load supplies or pump fuel. The initial total amount of supplies available to the task group at time of embarkation will have been computed during the previous formation phase computations. Let this total tonnage be denoted by S_e . If the Naval base's maximum loading rate is r_s (tons per day), then the time required to outfit the task group with supplies (t_{se}) will be given as follows:

$$t_{se} = \frac{S_e}{r_s} . \quad (31)$$

Similarly, if F_e denotes the total volume of fuel to be pumped aboard ships of the task group, and r_f is the maximum fuel pumping rate for the naval base, then the time required to pump fuel aboard the task group ships (t_{fe}) will be given as follows:

$$t_{fe} = \frac{F_e}{r_f} . \quad (32)$$

Thus, the time of embarkation (t_e) will be determined by the following equation:

$$t_e = \max(t_{se}, t_{fe}) . \quad (33)$$

An initial estimate of the time of arrival on-station of the task group, t_{di} , will also be computed during the formation phase computations. If d_o denotes the distance to the initial station from the naval base of embarkation, and v_a denotes the average speed of advance on deploying (both task group inputs), then this estimate of t_{di} will be computed as follows:

$$t_{di} = t_e + v_a d_o . \quad (34)$$

This value of t_d will be used in the physical deployment phase of the computations. Should ship or submarine fuel supplies be depleted below the critical levels, then the delay times encountered while deploying (determined in the Fuel Resource Readiness Area calculations) will be summed up, with this sum being denoted by t_{de} . The actual time of arrival on-station (t_d) will be determined by the following equation:

$$t_d = t_{di} + t_{de} \quad (35)$$

where t_{de} is zero if no fuel delays are encountered during the deployment of the task group. If this value of t_d is less than t_{dm} , the maximum time to arrive on station (a task group input), then the task group will be assigned an idle mission during the interval $(t_{dm} - t_d)$ and the lower bound on the readiness function integrals will be t_{dm} . On the other hand, if t_d is greater than t_{dm} , the lower bound of the integrals will be t_d and the task group will assume a zero readiness value for the time interval $(t_d - t_{dm})$. In either case, the time of completion of the task group's stay on-station (t_c) will be the following:

$$t_c = t_{dm} + T_d \quad (36)$$

where T_d is the task group's duration of deployment (a task group input). This value of t_c will represent the upper bound of the readiness function integrals to be used in the on-station phase of the computations. No deployment time factor computations are required during the on-station phase computations.

6. Readiness Computations

The support factor model will generate a large set of resource area readiness states computed on an overall task group basis that considers the effects, on the readiness of a task group in these resource areas, of various assumptions about the systems providing logistic support to the task group. These assumptions are embedded, in some detail, in the support factor inputs and, more generally, in the model construct itself. The approach used is quite broad in nature and does not consider the relative importance of the various operational capabilities of the ships required in the performance of the assigned task group operational missions, which themselves have a varying degree of relative importance to the overall mission of the task group. This section describes the manner by which these broad resource area readiness states are transformed into an estimate of the task group's overall readiness through a progression of transformations on up through the readiness hierarchy structure, beginning at the individual ship and aircraft squadron resource area level.

a. Unit Resource Area Readiness Assignments

The resource area readiness states generated by the support model are broken down according to various subarea/unit-type combinations--e.g., a resource area readiness state was generated for operations personnel assigned to surface units, and another resource area readiness state was generated for weapons systems equipment attached to air units. These readiness states are now transferred to the individual ships and aircraft squadrons in accordance with their unit-type applicability. The subarea segregation still remains intact because the performance of the various ship operational capabilities have been defined (for this model concept) in terms of the subareas within each resource area through the specification of relative importance factors.

The applicable readiness states transfer directly. For example, a destroyer would be assigned an operations personnel readiness state equal to the operations personnel readiness state for surface units generated by the support factor model. Similarly, the equipment readiness state for propulsion and navigation systems assigned to an attack submarine would be equal to the associated readiness state for subsurface units generated by the model.

b. Ship Operational Capabilities

The next step in the movement up the readiness hierarchy structure is to establish the readiness of the task group ships relative to their performance under the various ship operational capabilities. These readiness estimates are made only for ship type/operational capability combinations that are applicable to the set of operational missions assigned to the task group. These combinations will have been identified during the computation of the on-station load factors. That is, if a ship operational capability--say, MSO-5: conduct underwater recovery operations-- does not apply to any of the task group operational missions for a certain ship type, then no readiness estimate is made for that ship type/operational capability combination.

In the discussion that follows, the following notation is used:

- j = Index for task group ships ($j = 1, \dots, J$)
- a = Index for task group aircraft squadrons ($a = 1, \dots, A$)
- n_a = Indicator denoting the ship that aircraft squadron a is assigned to
- P_j = Personnel allowance for ship j
- P_a = Personnel allowance for aircraft squadron a
- k = Index for operational capabilities ($k = 1, \dots, K$)
- m = Index for ship resource subareas ($m = 1, \dots, M$)
- i = Index for operational mission types ($i = 1, \dots, I$)
- x_{ijk} = Relative importance of operational capability k in ship j 's performance of mission type i
- y_{jkm} = Relative importance of resource subarea m with respect to ship j 's readiness relative to operational capability k
- r_{jm} = Readiness state of ship j (without assigned aircraft squadrons) relative to resource subarea m
- r_{am} = Readiness state of aircraft squadron a relative to resource subarea m
- s_{jk} = Readiness state of ship j (with assigned aircraft squadrons) relative to operational capability k .

For clarity of presentation, it is assumed that the ship and aircraft squadron indices coincide with the respective ship type and aircraft squadron type indices identified in the data base.

The outputs of this computation section are the values of the s_{jk} . If $x_{ijk} = 0$, then s_{jk} is not computed. There are three different approaches that could be used to determine the values of the s_{jk} : series approach, weakest link approach, and weighted average approach. The choice of the specific approach would be left to the discretion of the user and would be specified as a model input. The applicable equations

for each approach are as follows, where it is noted that different equations are required for ships with aircraft complements than for those without aircraft complements:

- Series Approach (SA)

- Without Aircraft Complements

$$s_{jk} = \prod_{m=1}^M r_{jm} \cdot \quad (37)$$

$$\text{s.t. } y_{jkm} \neq 0$$

- With Aircraft Complements

$$s_{jk} = \prod_{m=1}^M r_{jm} \quad (38)$$

$$\text{s.t. } y_{jkm} \neq 0$$

if operational capability m is ship-only oriented;

$$s_{jk} = \prod_{m=1}^M \left(\frac{\sum_a p_a r_{am}}{\sum_a p_a} \right) \quad (39)$$

$$\text{s.t. } y_{jkm} \neq 0 \quad \text{s.t. } n_a = j$$

if operational capability m is aircraft-only oriented;

$$s_{jk} = \prod_{m=1}^M \left(\frac{P_j r_{jm} + \sum_a P_a r_{am}}{P_j + \sum_a P_a} \right) \quad (40)$$

$s.t. y_{jkm} \neq 0$
 $s.t. n_a = j$

if operational capability m is both ship and aircraft oriented.

- Weakest Link Approach (WLA)

- Without Aircraft Complements

$$s_{jk} = \min_m (r_{jm}). \quad (41)$$

$s.t. y_{jkm} \neq 0$

- With Aircraft Complements

$$s_{jk} = \min_m (r_{jm}). \quad (42)$$

$s.t. y_{jkm} \neq 0$

if operational capability m is ship-only oriented;

$$s_{jk} = \min_m \left(\frac{\sum_a P_a r_{am}}{\sum_a P_a} \right) \quad (43)$$

$s.t. y_{jkm} \neq 0$
 $s.t. n_a = j$

if operational capability m is aircraft-only oriented;

$$s_{jk} = \min_m \left(\frac{P_j r_{jm} + \sum_a P_a r_{am}}{P_j + \sum_a P_a} \right) \quad (44)$$

s.t. $y_{jkm} \neq 0$
s.t. $n_a = j$

if operational capability m is both ship and aircraft oriented.

• Weighted Average Approach

- Without Aircraft Complements

$$s_{jk} = \sum_{m=1}^M y_{jkm} r_{jm} \quad (45)$$

s.t. $y_{jkm} \neq 0$

- With Aircraft Complements

$$s_{jk} = \sum_{m=1}^M y_{jkm} r_{jm} \quad (46)$$

s.t. $y_{jkm} \neq 0$

if operational capability m is ship-only oriented;

$$s_{jk} = \sum_{m=1}^M y_{jkm} \left(\frac{\sum_a P_a r_{am}}{\sum_a P_a} \right) \quad (47)$$

s.t. $y_{jkm} \neq 0$
s.t. $n_a = j$

if operational capability m is aircraft-only oriented;

$$s_{jk} = \sum_{\substack{m=1 \\ \text{s.t. } y_{jkm} \neq 0}}^M y_{jkm} \left(\frac{P_j r_{jm} + \sum_a P_a r_{am}}{P_j + \sum_a P_a} \right) \quad (48)$$

$\text{s.t. } n_a = j$

if operational capability m is both ship and aircraft oriented. For the above approaches, if $s_{jk}(X)$ denotes the value computed by approach X ($X = SA, WLA, WAA$), then it should be noted that

$$s_{jk}(SA) \leq s_{jk}(WLA) \leq s_{jk}(WAA). \quad (49)$$

c. Ship Missions

With the readiness states of ships determined for the various ship operational capabilities, the next step up the readiness hierarchy structure is to determine the readiness of the ships relative to their performance under the various assigned task group operational missions. These readiness estimates are made only for ships whose importance factors relative to the performance of a task group mission are nonzero, as established in Subsection MRS-A of the data base.

In the presentation of the applicable equations, the following additional notation is used:

w_{ij} = Importance factor for ship j to the performance of mission type i

S_{ij} = Readiness state of ship j relative to the performance of mission type i .

The outputs of this computation section are the values of the S_{ij} . If $w_{ij} = 0$, then S_{ij} is not computed. As with the previous set of computations, the same three different approaches can be used to determine the values of the S_{ij} , with the choice left to the discretion of the user as specified by a model input:

- Series Approach (SA)

$$S_{ij} = \prod_{k=1}^K s_{jk} . \quad (50)$$

$$s.t. x_{ijk} \neq 0$$

- Weakest Link Approach (WLA)

$$S_{ij} = \min_k (s_{jk}) . \quad (51)$$

$$s.t. x_{ijk} \neq 0$$

- Weighted Average Approach (WAA)

$$S_{ij} = \sum_{k=1}^K x_{ijk} s_{jk} . \quad (52)$$

$$s.t. x_{ijk} \neq 0$$

As with the computations for the s_{jk} , the same inequality for the values of the S_{ij} computed under the three approaches holds true. That is,

$$S_{ij}^{(SA)} \leq S_{ij}^{(WLA)} \leq S_{ij}^{(WAA)} . \quad (53)$$

d. Task Group Operational Missions

The next step in the movement up the readiness hierarchy structure is to determine the readiness of the task group as a whole relative to its performance of the assigned operational missions. For each ship in the task group, an importance factor (W_{ij}) is specified in

the data base relative to that ship's relative contribution to the task group's performance of the mission. For a specific task group configuration and operational mission, a ship's relative importance will depend on the numbers and types of other ships in the task group. The relative importance of each ship in the task group thus depends on the magnitudes of the importance factors of the other ships in the task group. If W'_{ij} denotes the relative importance for the ship j relative to operational mission type i , then this value is given as follows:

$$W'_{ij} = \frac{W_{ij}}{\sum_{j=1}^J W_{ij}} \quad (54)$$

With the values of the W'_{ij} established, then the readiness state of the task group for operational mission i , denoted by R_i , can be determined by the three different approaches, the choice of which is subject to the discretion of the user as specified by a model input. The applicable equations are given as follows:

- Series Approach (SA):

$$R_i = \prod_{j=1}^J S_{ij} \cdot \quad (55)$$

s.t. $W'_{ij} \neq 0$

- Weakest Link Approach (WLA):

$$R_i = \min_j (S_{ij}) \cdot \quad (56)$$

s.t. $W'_{ij} \neq 0$

• Weighted Average Approach (WAA):

$$R_i = \sum_{j=1}^J w'_{ij} S_{ij} \cdot \quad (57)$$

s.t. $w'_{ij} \neq 0$

As with the previous computations of the intermediate readiness states, the following inequality hold true:

$$R_i(SA) \leq R_i(WLA) \leq R_i(WAA) \cdot \quad (58)$$

e. Task Group

The final step in the movement up the readiness hierarchy structure is to determine the overall readiness of the task group relative to its assigned set of operational missions. Specified as task group inputs are the estimated frequency of operational mission type i , denoted by f_i , and the relative importance w_i of that mission type in relation to the other mission types. If the task group arrived on-station after time t_{dm} , the input value of the maximum time to arrive on station, then the task group will have initial period T_{nr} of zero readiness, with

$$T_{nr} = t_d - t_{dm} \quad (59)$$

where t_d is the actual time of arrival on-station. Of course, if $t_d \leq t_{dm}$, then $T_{nr} = 0$. If T_d denotes the planned duration of the task group's on-station deployment, given as a task group input, then the task group's overall readiness \bar{R} can be determined by the following equation:

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$$\bar{R} = \frac{T_d - T_{nr}}{T_d} \sum_{i=1}^I f_i w_i R_i. \quad (60)$$

This value of \bar{R} for the task group's overall readiness is the ultimate output obtained from the model.

IV MODEL APPLICATION AND IMPLEMENTATION

A. Application

The readiness evaluation model concept described in the previous chapter would, if implemented, serve as a convenient tool for evaluating readiness of postulated task group configurations under various assumptions relative to the performance of the logistic systems that provide support to the task group. Of primary importance would be the estimation of the effects, on task group readiness, of postulated modifications and improvements to existing or planned logistic support systems and procedures. For example, a support factor data base could be established that represents the performance of existing or planned logistic support systems. Modifications and improvements to these systems could be represented through variations in the values of the data base support factor inputs. For a specific task group deployment, the model could be exercised using the data base support factor inputs and also using the revised support factor inputs. The differences in the model output values of the task group overall readiness would then provide a basis for determining the relative worth of implementing the proposed changes in the logistic support systems.

Since the logistic support systems are designed to provide support for not just one task group deployment, but for task group deployments in general, postulated changes in logistic support systems should be evaluated through their effects on readiness of a variety of representative task group deployments. For example, one such representative deployment could be a task group deployed in the Indian Ocean conducting presence operations for 90 days, while another could be a task group deployed in the Caribbean conducting a 45-day blockade. Thus, if a set of proposed support system changes is being considered--say, those that would result in the future from present funding of alternative exploratory development (ED) funding programs--the choice of which alternative ED funding program would produce the greatest improvement in task group readiness

should be based on readiness evaluations for a variety of projected task group deployments. If one such funding program provided the greatest readiness improvement for each projected deployment, then that alternative would dominate and thus be the preferred alternative for application of ED funds. However, in most cases, a single alternative will not be dominant. That is, one alternative may provide the greatest increase in readiness for a specific deployment, whereas another alternative may do likewise for another deployment. Assuming that the projected deployments are significantly different from one another, then the relative worth of changes in readiness among the different task groups may not be comparable on the surface. For a large number of projected deployments, this would especially hold true. In this case, the technical strategist, who establishes the allocation of ED funds, would require the use of a method for allocating resources to projects where the expected payoffs of these proposed projects are measured in terms of the various readiness states for alternative deployments. One such resource allocation method that addresses this problem is that developed by SRI for DTNSRDC.¹⁹ This method for decision making was developed to specifically address the question of how to compare alternatives whose expected outcomes are multifaceted; that is, they are evaluated in terms of diverse and disparate measures of effectiveness (MOEs)--i.e., readiness states of alternative task group deployments. The method relies heavily on the subjective but informed judgment of a decision maker (DM). It assumes that the DM has a subjective model relating the needs of the Navy to fulfill its mission, the various logistics MOEs that assess the Navy's capability to carry out this mission, and the effects of improvements in these MOEs on this capability. The method allows the DM to progressively build up and communicate his preferences concerning specific ED programs and their expected outcomes expressed as achievable levels of important MOEs. He does this through a sequence of MOE tradeoff assessments between two alternatives that differ only in the values of two MOEs. These tradeoff assessments result in the construction of a sequence of hypothetical alternatives that link two real alternatives, and allow the inference of a preference (or ranking) between these two alternatives. Systematically, applying this approach sequentially to all available alternatives results in a

relative ranking among them. The coupling of the readiness evaluation model to this resource allocation method would provide a significant reduction in the inherent subjectivity of the original resource allocation method.

B. Implementation

The implementation of the evaluation model concept would require a significant effort, both in the actual programming of the model and also in the data gathering activity to establish the required model data base, which would include a support factor data base as well as the mission requirements and support requirements data base. However, once this implementation has been established, the benefits derived from the use of the model will far offset the cost of this initial investment.

Prior to implementation it is advised that a careful review of the various model assumptions be made by Navy department personnel knowledgeable in the area of task group readiness. Such a review should cover the various components defined in the readiness hierarchy structure (described in Section III-B) to ensure that they are indeed the most appropriate to be used in addressing readiness. Additionally, the support factor model (described in Section III-C-5) represents an initial attempt at relating logistic support factors to unit resource area readiness and is certain to have omitted or inefficiently represented specific logistic support functions. A detailed review would uncover these discrepancies, and would lead to a more efficient and credible support factor model. Replacement of many of the linear functions assumed in the model description by nonlinear functions would be one such worthwhile improvement. Another area of improvement might be to couple components of the individual readiness functions where independence was assumed, but dependence is more likely the case. Also, the integration process for the readiness estimates, assumed at the unit resource area level, could possibly be performed at a higher level, thus requiring readiness functions to be maintained up through higher levels in the readiness hierarchy structure. These only represent a small sample of suggested improvement options that might result from a careful model review.

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